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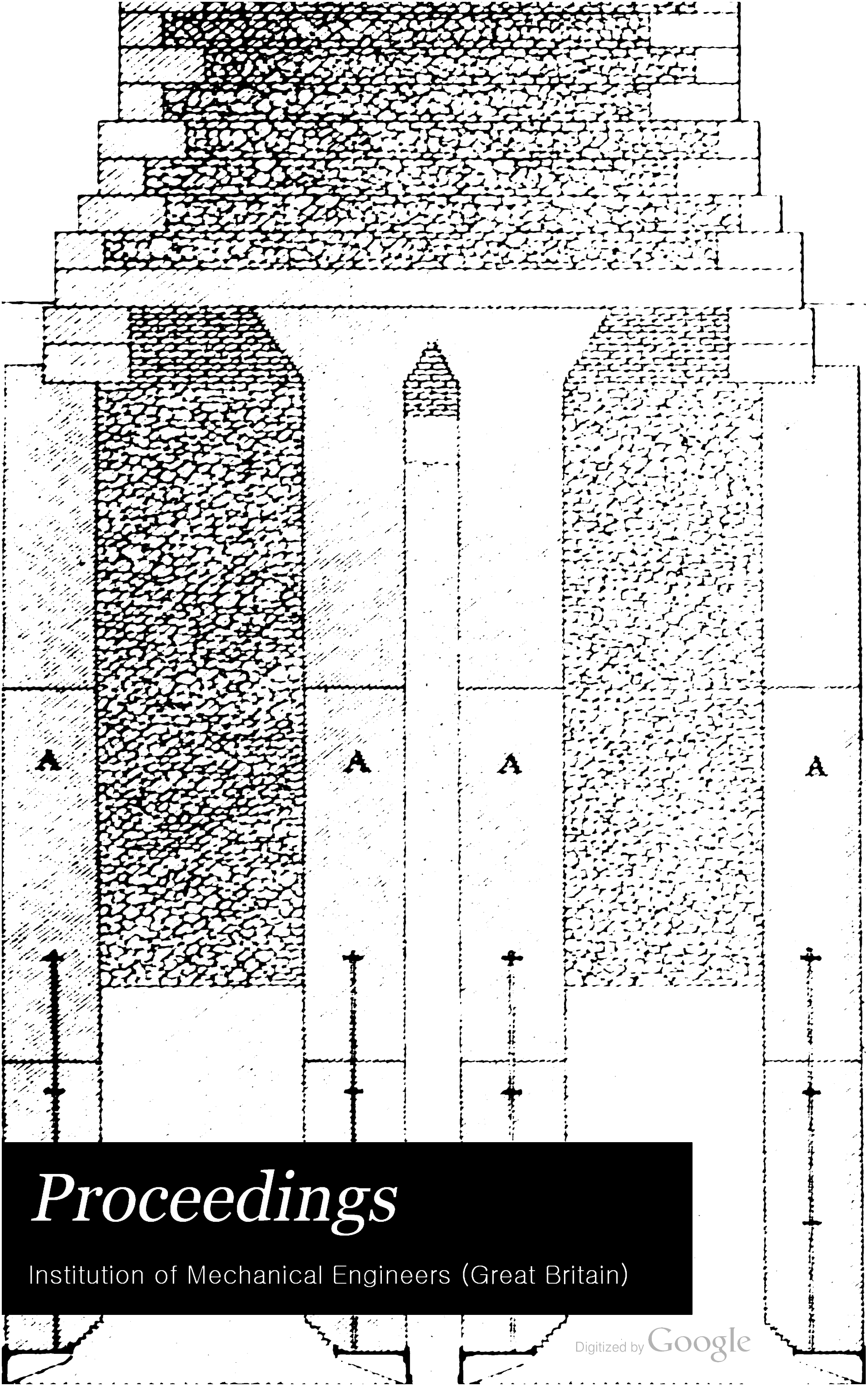

Proceedings

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MECHANICAL ENGINEERS.

PROCEEDINGS.

1863.

PUBLISHED BY THE INSTITUTION,
81 Newhall Street, Birmingham.

BIRMINGHAM:
PRINTED AT MARTIN BILLING, SON, AND CO.'S STEAM-PRESS OFFICES,
LIVERY STREET.

INDEX.

1863.

PAGE
Annual Report 1
Glass, Plate, Machinery for Manufacture of, by G. H. Daglish . . 209
Glass, Polished Sheet, Manufacture of, by R. Pilkington 268
Iron Ships, Construction of, by J. Vernon 115
Iron Works at Grosmont, New, by H. C. Coulthard 225
Locomotive Engines in International Exhibition of 1862, by D. K. Clark 78
Memoirs of Members deceased in 1862 13
Piers, Apparatus for Sinking, for Indian Railway Bridges, by J. F. Strong 16
Pumping Engine, Cornish, with Wrought Iron Beam, and Pit Work at Clay Cross Colliery, by W. Howe 248
Spinning Machinery, Drawing Rollers for, Construction of, by W. Weild 59
Subjects for Papers 5
Surface Condensers, Effects of, on Steam Boilers, by J. Jack 150
Type Composing and Distributing Machine, by W. H. Mitchel . . 34
Ventilation and Warming, Mechanical, of St. George's Hall, Liverpool, by W. Mackenzie 194
Water Works, Liverpool, Mechanical Features of, by T. Duncan . . 167

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LIST OF MEMBERS,

WITH YEAR OF ELECTION.

1863.

LIFE MEMBERS.

1858. Bower, John Wilkes, Lancashire and Yorkshire Railway, Engineer's Office, Manchester.
1852. Brogden, Henry, Sale, near Manchester.
1858. Fletcher, Henry Allason, Lowca Engine Works, Whitehaven.
1857. Haughton, S. Wilfred, 62 Lower Baggot Street, Dublin.
1854. Lloyd, George Braithwaite, Messrs. Lloyds, High Street, Birmingham.
1853. Maudslay, Henry, Cheltenham Place, Lambeth, London, S.
1848. Penn, John, The Cedars, Lee, Kent, S.E.
1863. Wicksteed, Thomas, 4 Great Queen Street, Westminster, S.W.

MEMBERS.

1861. Abel, Charles Denton, 20 Southampton Buildings, London, W.C.
1848. Adams, William Alexander, Midland Works, Birmingham.
1859. Adamson, Daniel, Newton Moor Iron Works, Hyde, near Manchester.
1861. Addenbrooke, George, Rough Hay Furnaces, Darlaston, near Wednesbury.
1851. Addison, John, 6 Delahay Street, Westminster, S.W.
1858. Albaret, Auguste, Engine Works, Liancourt, Oise, France.
1847. Allan, Alexander, Locomotive Superintendent, Scottish Central Railway, Perth.
1856. Allen, James, Cambridge Street Works, Manchester.
1859. Alton, George, Midland Railway Works, Derby.
1861. Amos, Charles Edwards, Grove Works, Southwark, London, S.E.
1856. Anderson, John, Assistant Superintendent, Royal Gun Factories, and Inspector of Machinery to the War Department, Royal Arsenal, Woolwich, S.E.
1856. Anderson, William, Messrs. Courtney Stephens and Co., Blackall Place Iron Works, Dublin.
1862. Angus, Robert, Locomotive Superintendent, North Staffordshire Railway, Stoke-upon-Trent.

1858. Appleby, Charles Edward, Mining Engineer, 3 London Terrace, Derby.
1861. Armitage, Harry W., Farnley Iron Works, Leeds.
1859. Armitage, William James, Farnley Iron Works, Leeds.
1863. Armstrong, John, Timber Works, 20 North Bridge Street, Sunderland.
1857. Armstrong, Joseph, Great Western Railway, Locomotive Department, Wolverhampton.
1858. Armstrong, Sir William George, Elswick, Newcastle-on-Tyne.
1857. Ashbury, James Lloyd, Openshaw Works, near Manchester.
1848. Ashbury, John, Openshaw Works, near Manchester.
1858. Atkinson, Charles, Fitzalan Steel Works, Sheffield.

1848. Bagnall, William, Gold's Hill Iron Works, Westbromwich.
1860. Bailey, Samuel, Mining Engineer, The Pleck, near Walsall.
1860. Barclay, John, Bowling Iron Works, near Bradford, Yorkshire.
1860. Barker, Paul, Old Park Iron Works, Wednesbury.
1863. Barlow, Edward, Messrs. Dobson and Barlow, Machine Works, Bolton.
1862. Barrow, Joseph, 93 Argyle Terrace, Bristol Street, Hulme, Manchester.
1862. Barton, Edward, 1 Market Street, Manchester.
1847. Barwell, William Harrison, Eagle Foundry, Northampton.
1859. Bastow, Samuel, Cliff House Iron Works, West Hartlepool.
1860. Batho, William Fothergill, Messrs. Nettlefold and Chamberlain, Smethwick Screw Works, Birmingham.
1859. Beacock, Robert, Victoria Foundry, Leeds.
1860. Beale, William Phipson, Westbourne Road, Edgbaston, Birmingham.
1848. Beattie, Joseph, Locomotive Superintendent, London and South Western Railway, Nine Elms, London, S.
1859. Beck, Edward, Messrs. Neild and Co., Dallam Iron Works, Warrington.
1860. Beck, Richard, Lister Works, Upper Holloway, London, N.
1862. Beckett, Henry, Mining Engineer, Upper Penn, Wolverhampton.
1858. Bell, Isaac Lowthian, Clarence Felling and Wylam Iron Works, Newcastle-on-Tyne.
1857. Bellhouse, Edward Taylor, Eagle Foundry, Hunt Street, Oxford Street, Manchester.
1854. Bennett, Peter Duckworth, Spon Lane Iron Foundry, Westbromwich.
1861. Bessemer, Henry, 4 Queen Street Place, New Cannon Street, London, E.C.
1847. Beyer, Charles F., Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.
1861. Binns, Charles, Mining Engineer, Clay Cross, near Chesterfield.
1863. Birckel, John James, Vauxhall Foundry, Liverpool.
1847. Birley, Henry, Haigh Foundry, near Wigan.
1856. Blackburn, Isaac, Witton Park Iron Works, Darlington.
1851. Blackwell, Samuel Holden, Russell's Hall Iron Works, near Dudley.

1862. **Blake**, Henry Wollaston, Messrs. James Watt and Co., 18 London Street, London, E.C.

1862. **Blyth**, Alfred, Steam Engine Works, Fore Street, Limehouse, London, E.

1863. **Boeddinghaus**, Julius, Messrs. Heinrich Boeddinghaus and Sons, Elberfeld, Prussia.

1862. **Bouch**, Thomas, 78 George Street, Edinburgh.

1858. **Bouch**, William, Shildon Engine Works, Darlington.

1847. **Bovill**, George Hinton, 24 Duke Street, Westminster, S.W.

1862. **Boyd**, Nelson, Mining Engineer, Hartington, near Ashbourne.

1854. **Bragge**, William, Atlas Steel and Iron Works, Sheffield.

1854. **Bramwell**, Frederick Joseph, 35A Great George Street, Westminster, S.W.

1856. **Bray**, Edwin, Nevill Holt, near Market Harborough.

1861. **Brierly**, Henry, 27 Southampton Buildings, London, W.C.

1848. **Broad**, Robert, Horseley Iron Works, near Tipton.

1863. **Brown**, Henry, Metropolitan Carriage and Wagon Company, Saltley Works, Birmingham.

1847. **Brown**, James, Jun., Messrs. James Watt and Co., Soho Foundry, near Birmingham.

1850. **Brown**, John, Atlas Steel and Iron Works, Sheffield.

1855. **Brown**, John, Mining Engineer, Barnsley.

1853. **Brown**, Ralph, Patent Shaft Works, Wednesbury.

1863. **Brown**, William Steel, Locomotive Superintendent, Edinburgh and Glasgow Railway, Cowlairs, Glasgow.

1858. **Burn**, Henry, Midland Railway, Locomotive Department, Derby.

1856. **Butler**, Ambrose Edmund, Kirkstall Forge, Leeds.

1863. **Butler**, Arthur, Surdah, Radshye, Lower Bengal, India: (or care of Walter Butler, Charing Cross Railway Works, Belvedere Road, Lambeth, London, S.)

1859. **Butler**, John, Old Foundry, Stanningley, near Leeds.

1859. **Butler**, John Octavius, Kirkstall Forge, Leeds.

1857. **Cabry**, Joseph, 39 Marylebone Road, London, N.W.

1847. **Cabry**, Thomas, North Eastern Railway, York.

1847. **Cammell**, Charles, Cyclops Steel Works, Sheffield.

1860. **Cannell**, Fleetwood James, Old Park Iron Works, Wednesbury.

1860. **Carbutt**, Edward Hamer, Vulcan Iron Works, Thornton Road, Bradford, Yorkshire.

1862. **Carpmael**, William, 24 Southampton Buildings, London, W.C.

1856. **Carrett**, William Elliott, Sun Foundry, Leeds.

1858. **Carson**, James Irving, Locomotive Superintendent, West Hartlepool Harbour and Railway, Stockton-on-Tees.

1849. **Chamberlain**, Humphrey, 3 St. John's, Wakefield.

1857. Chrimes, Richard, Brass Works, Rotherham.
1854. Clark, Daniel Kinnear, 11 Adam Street, Adelphi, London, W.C.
1859. Clark, George, Monkwearmouth Engine Works, Sunderland.
1862. Clark, James, Wellington Foundry, Leeds.
1859. Clay, William, Mersey Steel and Iron Works, Sefton Street, Liverpool.
1863. Clayton, Robert, Soho Foundry, Preston.
1847. Clift, John Edward, Durnford Place, Coventry Road, Birmingham.
1860. Clunes, Thomas, Vulcan Iron Works, Worcester.
1847. Cochrane, Alexander Brodie, Woodside Iron Works, near Dudley.
1858. Cochrane, Charles, Woodside Iron Works, near Dudley.
1860. Cochrane, Henry, Ormesby Iron Works, Middlesborough.
1854. Cochrane, John, Woodside Iron Works, near Dudley.
1847. Coke, Richard George, Mining Engineer, 6 Market Hall Chambers, Chesterfield.
1853. Cooper, Samuel Thomas, Leeds Iron Works, Leeds.
1860. Cope, James, Mining Engineer, Pensnett, near Dudley.
1848. Corry, Edward, 8 New Broad Street, London, E.C.
1857. Cortazzi, Francis James, Locomotive Superintendent, Great Indian Peninsula Railway, Bombay, India: (or care of T. D. Hornby, 3 Brunswick Street, Liverpool.)
1860. Coulthard, Hiram Craven, Park Iron Works, Blackburn.
1847. Cowper, Edward Alfred, 35A Great George Street, Westminster, S.W.
1862. Cox, Samuel H. F., 6 St. John's Road, Putney, London, S.W.
1863. Craig, Andrew, Rock Ferry, Birkenhead.
1847. Crampton, Thomas Russell, 12 Great George Street, Westminster, S.W.
1858. Crawhall, Joseph, St. Ann's Wire and Hemp Rope Works, Newcastle-on-Tyne.
1857. Criswick, Theophilus, Lydbrook Deep Level Collieries, near Ross.
1863. Crow, George, Messrs. R. Stephenson and Co., South Street, Newcastle-on-Tyne.
1858. Cubitt, Charles, 3 Great George Street, Westminster, S.W.

1863. Davy, Alfred, Park Iron Works, Sheffield.
1849. Dawes, George, Milton and Elsecar Iron Works, near Barnsley.
1860. Dawes, William Henry, Bromford Iron Works, Westbromwich.
1861. Dawson, Benjamin, South Hetton, near Fence Houses.
1862. Deakin, William, Monmer Lane Iron Works, Willenhall, near Wolverhampton.
1857. De Bergue, Charles, Strangeways Iron Works, Manchester.
1858. Dees, James, Whitehaven.
1858. Dempsey, William, 26 Great George Street, Westminster, S.W.
1859. Dixon, John, Railway Foundry, Bradford, Yorkshire.

1861. Dixon, Thomas, Low Moor Iron Works, near Bradford, Yorkshire.
1857. Douglas, George K., Messrs. R. Stephenson and Co., South Street, Newcastle-on-Tyne.
1857. Dove, George, St. Nicholas and Woodbank Iron Works, Carlisle.
1847. Dubs, Henry, 5 Dixon Street, Glasgow.
1856. Dudgeon, John, Sun Iron Works, Millwall, London, E.
1856. Dudgeon, William, Sun Iron Works, Millwall, London, E.
1857. Dunlop, John Macmillan, Marlborough Street, Oxford Street, Manchester.
1854. Dunn, Thomas, Windsor Bridge Iron Works, Manchester.
1861. Dutton, Charles, Bromford Iron Works, Westbromwich.
1860. Dyson, George, Tudhoe Iron Works, near Ferryhill.

1859. Eassie, Peter Boyd, Saw Mills, High Orchard, Gloucester.
1858. Easton, Edward, Grove Works, Southwark, London, S.E.
1856. Eastwood, James, Railway Iron Works, Derby.
1862. Elder, John, Messrs. Randolph Elder and Co., Centre Street, Glasgow.
1859. Elliot, George, Houghton-le-Spring, near Fence Houses.
1860. Elwell, Thomas, Messrs. Varrall Elwell and Poulot, 9 Avenue Trudaine, Paris.
1853. England, George, Hatcham Iron Works, London, S.E.
1861. Esson, William, Engineer, Cheltenham Gas Works, Cheltenham.
1857. Evans, John Campbell, Morden Iron Works, East Greenwich, S.E.
1848. Everitt, George Allen, Kingston Metal Works, Adderley Street, Birmingham.

1857. Fairlie, Robert Francis, 56 Gracechurch Street, London, E.C.
1862. Farmer, John, Shut End Iron Works, near Dudley.
1861. Fearnley, Thomas, Globe Works, Hall Lane, Bradford, Yorkshire.
1847. Fenton, James, Low Moor Iron Works, near Bradford, Yorkshire.
1854. Fernie, John, Clarence Iron Works, Leeds.
1862. Field, Joshua, Cheltenham Place, Lambeth, London, S.
1861. Field, Joshua, Jun., Cheltenham Place, Lambeth, London, S.
1861. Fleetwood, Daniel Joseph, Metal Rolling Mills, Icknield Port Road, Birmingham.
1847. Fletcher, Edward, Locomotive Superintendent, North Eastern Railway, Gateshead.
1857. Fletcher, James, Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.
1859. Fogg, Robert, 17 Park Street, Westminster, S.W.
1861. Forster, Edward, Spon Lane Glass Works, near Birmingham.
1849. Forsyth, John C., North Staffordshire Railway, Stoke-upon-Trent.
1861. Foster, Sampson Lloyd, Old Park Iron Works, Wednesbury.

1847. Fothergill, Benjamin, 27 Cornhill, London, E.C.
1847. Fowler, John, 2 Queen Square Place, Westminster, S.W.
1857. Fowler, John, Steam Plough Works, Leeds.
1847. Fox, Sir Charles, 8 New Street, Spring Gardens, London, S.W.
1859. Fraser, John, 18 York Place, Leeds.
1853. Fraser, Joseph Boyes, Alma Place, Kenilworth.
1856. Freeman, Joseph, 22 Cannon Street, London, E.C.
1852. Froude, William, Elmsleigh, Paignton, Torquay.

1862. Galton, Capt. Douglas, R.E., War Office, Pall Mall, London, S.W.
1847. Garland, William S., Messrs. James Watt and Co., Soho Foundry, near Birmingham.
1848. Gibbons, Benjamin, Hill Hampton House, near Stourport.
1860. Gibbons, Benjamin, Jun., Athol House, Edgbaston, Birmingham.
1856. Gilkes, Edgar, Tees Engine Works, Middlesborough.
1862. Godfrey, Samuel, Messrs. Bolckow and Vaughan's Iron Works, Middlesborough.
1854. Goode, Benjamin W., St. Paul's Square, Birmingham.
1847. Goodfellow, Benjamin, Hyde Iron Works, Hyde, near Manchester.
1848. Green, Charles, Tube Works, Leek Street, Birmingham.
1861. Green, Edward, Jun., 3 Bank Street, Exchange, Manchester.
1858. Greenwood, Thomas, Albion Works, Leeds.
1857. Gregory, John, Engineer, Portuguese National Railway South of Tagus, Barriero, near Lisbon, Portugal.
1860. Grice, Frederic Groom, Stour Valley Works, Spon Lane, Westbromwich.

1861. Haden, William, Dixon's Green, Dudley.
1861. Haggie, Peter, Hemp and Wire Rope Works, Gateshead.
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1859. Harman, Henry William, Canal Street Works, Manchester.
1856. Harrison, George, Millwall Iron Works, London, E.
1858. Harrison, Thomas Elliot, North Eastern Railway, Newcastle-on-Tyne.
1863. Hartas, Isaac, Rosedale Iron Mines, near Pickering, Yorkshire.
1858. Haswell, John A., North Eastern Railway, Locomotive Department, Gateshead.
1861. Hawkins, William Bailey, 14 George Street, Mansion House, London, E.C.
1856. Hawksley, Thomas, 30 Great George Street, Westminster, S.W.

1848. **Hawthorn, Robert**, Forth Banks, Newcastle-on-Tyne.
1848. **Hawthorn, William**, Forth Banks, Newcastle-on-Tyne.
1862. **Haynes, Thomas John**, Engineer and Shipbuilder, Puntales, Cadiz, Spain: (or care of B. G. Haynes, 154 Pailey Road, Glasgow.)
1860. **Head, John**, Messrs. Ransomes and Sims, Orwell Works, Ipswich.
1858. **Head, Thomas Howard**, Teesdale Iron Works, Stockton-on-Tees.
1853. **Headly, James Ind**, Eagle Works, Cambridge.
1857. **Healey, Edward Charles**, 163 Strand, London, W.C.
1862. **Heath, William J. W.**, Assistant Engineer, Ceylon Railway, Colombo, Ceylon: (or care of John J. Heath, 105 Vyse Street, Birmingham.)
1860. **Heaton, George**, Royal Copper Mint, Icknield Street East, Birmingham.
1858. **Hedley, John**, 4 High Swinburn Place, Newcastle-on-Tyne.
1848. **Hewitson, William Watson**, Airedale Foundry, Leeds.
1863. **Hind, Roger**, Scotland Bank Iron Works, Warrington.
1862. **Hingley, Samuel**, Hart's Hill Iron Works, near Brierley Hill.
1858. **Hodgson, Robert**, North Eastern Railway, Newcastle-on-Tyne.
1852. **Holcroft, James**, Shut End, Brierley Hill.
1863. **Holt, Frank**, Gorton Foundry, Manchester.
1848. **Homersham, Samuel Collett**, 19 Buckingham Street, Adelphi, London, W.C.
1860. **Hopkins, James Innes**, Tees Side Iron Works, Middlesborough.
1856. **Hopkinson, John**, London Road Iron Works, Manchester.
1858. **Hopper, George**, Houghton-le-Spring Iron Works, near Fence Houses.
1858. **Horsley, William, Jun.**, Hartley Engine Works, Seaton Sluice, near North Shields.
1851. **Horton, Joshua**, Ætna Works, Smethwick, near Birmingham.
1858. **Hosking, John**, Gateshead Iron Works, Gateshead.
1860. **Howard, James**, Britannia Iron Works, Bedford.
1860. **Howe, William**, Clay Cross Coal and Iron Works, near Chesterfield.
1847. **Howell, Joseph**, Hawarden Iron Works, Holywell.
1861. **Howell, Joseph Bennett**, Hartford Steel Works, Sheffield.
1862. **Huber, Peter Emile**, Vogelhutte, Zurich, Switzerland.
1861. **Huffam, Frederick Thomas**, Avonside Iron Works, Bristol.
1847. **Humphrys, Edward**, Deptford Pier, London, S.E.
1859. **Hunt, James P.**, Corngreaves Iron Works, Corngreaves, near Birmingham.
1856. **Hunt, Thomas**, Tudela and Bilbao Railway, Bilbao, Spain: (or 3 Stanley Place, Preston.)
1862. **Hunter, Michael, Jun.**, Talbot Works, Johnson Street, Sheffield.
1860. **Hurry, Henry C.**, Engineer, Great Western Railway, Worcester.
1863. **Hutton, Walter Stuart**, Prospect Works, Hunslet Lane, Leeds.

1857. **Inshaw, John**, Engine Works, Morville Street, Birmingham.

1859. Jackson, Matthew Murray, Messrs. Escher Wyss and Co., Engine Works, Zurich, Switzerland.

1847. Jackson, Peter Rothwell, Salford Rolling Mills, Manchester.

1861. Jackson, Robert, Ætna Steel Works, Sheffield.

1860. Jackson, Samuel, Cyclops Steel Works, Sheffield.

1858. Jaffrey, George William, Hartlepool Iron Works, Hartlepool.

1856. James, Jabez, 28A Broadwall, Stamford Street, Lambeth, London, S.

1855. Jeffcock, Parkin, Mining Engineer, Midland Road, Derby.

1861. Jeffcock, Thomas William, Mining Engineer, 18 Bank Street, Sheffield.

1863. Jeffreys, Edward A., Low Moor Iron Works, near Bradford, Yorkshire.

1857. Jenkins, William, Locomotive Superintendent, Lancashire and Yorkshire Railway, Miles Platting, Manchester.

1861. Jessop, Sydney, Park Steel Works, Sheffield.

1861. Jessop, Thomas, Park Steel Works, Sheffield.

1854. Jobson, John, Derwent Foundry, Derby.

1863. Johnson, Bryan, Flookersbrook Foundry, Chester.

1847. Johnson, James, 4 Park Place, Leeds.

1848. Johnson, Richard William, Oldbury Carriage Works, near Birmingham.

1861. Johnson, Samuel Waite, Engineer, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.

1855. Johnson, William Beckett, Woodland's Bank, Altrincham, near Manchester.

1861. Jones, Alfred, Ettingshall Iron Works, Bilston.

1861. Jones, David, Engineer, Rumney Railway, Machen, near Newport, Monmouthshire.

1847. Jones, Edward, Old Park Iron Works, Wednesbury.

1857. Jones, John Hodgson, 26 Great George Street, Westminster, S.W.

1853. Joy, David, Cleveland Engine Works, Middlesborough.

1857. Kay, James Clarkson, Phœnix Foundry, Bury, Lancashire.

1857. Kendall, William, Locomotive Superintendent, Blyth and Tyne Railway, Percy Main, near Newcastle-on-Tyne.

1863. Kennan, James, Agricultural Implement Works, 19 Fishamble Street, Dublin.

1847. Kennedy, James, Cressington Park, Aigburth, Liverpool.

1857. Kennedy, Lt.-Colonel John Pitt, Engineer, Bombay Baroda and Central Indian Railway; 10 Liverpool Street, New Broad Street, London, E.C.

1863. Kennedy, John Pitt, Bombay Baroda and Central Indian Railway; 10 Liverpool Street, New Broad Street, London, E.C.

1848. Kirkham, John, 109 Euston Road, London, N.W.

1847. Kirtley, Matthew, Locomotive Superintendent, Midland Railway, Derby.

1859. Kitson, Frederick William, Monkbridge Iron Works, Leeds.

1848. Kitson, James, Airedale Foundry, Leeds.

1859. Kitson, James, Jun., Monkbridge Iron Works, Leeds.
1863. Knight, Thomas, 131 Bradford Street, Birmingham.
1862. Knott, Joseph, Pennington Cotton Mill, Leigh, near Manchester.

1863. Lancaster, John, Kirkless Hall Coal and Iron Works, near Wigan.
1863. Latham, Ernest, 40 Parliament Street, Westminster, S.W.
1860. Law, David, Phœnix Iron Works, Glasgow.
1857. Laybourn, John, Isca Foundry, Newport, Monmouthshire.
1856. Laybourn, Richard, Locomotive Superintendent, Monmouthshire Railway and Canal Company, Newport, Monmouthshire.
1860. Lea, Henry, 33 Waterloo Street, Birmingham.
1862. Lee, J. C. Frank, 30 Parliament Street, Westminster, S.W.
1860. Lee, John, Midland Railway, Locomotive Department, Derby.
1863. Lees, Samuel, Jun., Park Bridge Iron Works, Ashton-under-Lyne.
1863. Leigh, Evan, Miles Platting, Manchester.
1858. Leslie, Andrew, Iron Ship Building Yard, Hebburn Quay, Gateshead.
1856. Levick, Frederick, Cwm-Celyn Blaina and Coalbrook Vale Iron Works, near Newport, Monmouthshire.
1860. Lewis, Thomas William, Plymouth Iron Works, Merthyr Tydvil.
1856. Linn, Alexander Grainger, 2 Queen Square Place, Westminster, S.W.
1857. Little, Charles, Birksland Works, Bradford, Yorkshire.
1863. Lloyd, Edward R., Albion Tube Works, Nile Street, Birmingham.
1862. Lloyd, John, Lilleshall Iron Works, near Wellington, Shropshire.
1847. Lloyd, Sampson, Old Park Iron Works, Wednesbury.
1852. Lloyd, Samuel, Old Park Iron Works, Wednesbury.
1862. Lloyd, Wilson, Old Park Iron Works, Wednesbury.
1863. Loam, Matthew Hill, Engineer, Gas and Water Works, Nottingham.
1856. Longridge, Robert Bewick, Steam Boiler Assurance Company, 67 King Street, Manchester.
1859. Lord, Thomas Wilks, 2A Alfred Street, Boar Lane, Leeds.
1861. Low, George, Millgate Iron Works, Newark.
1854. Lynde, James Gascoigne, Town Hall, Manchester.

1856. Mackay, John, Mount Hermon, Drogheda.
1859. Manning, John, Boyne Engine Works, Hunslet, Leeds.
1862. Mansell, Richard Christopher, South Eastern Railway, Carriage Department, Ashford.
1862. Mappin, Frederick Thorpe, Sheaf Works, Sheffield.
1857. March, George, Union Foundry, Leeds.
1856. Markham, Charles, Staveley Coal and Iron Works, Staveley, near Chesterfield.
1848. Marshall, Edwin, Britannia Carriage Works, Birmingham.

1862. Marshall, James, Bunker Hill, Fence Houses.
1859. Marshall, William Ebenezer, Sun Foundry, Leeds.
1847. Marshall, William Prime, 81 Newhall Street, Birmingham.
1859. Marten, Edward Bindon, Stourbridge Water Works, 13 High Street, Stourbridge.
1860. Marten, George Priestley, 13 Morden Road, Blackheath Park, London, S.E.
1853. Marten, Henry, Parkfield Iron Works, near Wolverhampton.
1857. Martindale, Capt. Ben Hay, R.E., War Office, Pall Mall, London, S.W.
1854. Martineau, Francis Edgar, Globe Works, Cliveland Street, Birmingham.
1857. Masselin, Armand, 16 Rue Dauphine, Paris.
1853. Mathews, William, Corbyn's Hall Iron Works, near Dudley.
1848. Matthew, John, Messrs. John Penn and Co., Marine Engineers, Greenwich, S.E.
1847. Matthews, William Anthony, Sheaf Works, Sheffield.
1861. May, Robert Charles, 3 Great George Street, Westminster, S.W.
1857. May, Walter, Suffolk Works, Berkley Street, Birmingham.
1860. Mayer, Joseph, Iron Ship Builder, Linz, Austria: (or care of William Seyd, 69 Hatton Garden, London, E.C.)
1859. Maylor, William, East Indian Iron Company, Beypoor, India: (or care of E. J. Burgess, Abchurch Chambers, Abchurch Yard, London, E.C.)
1847. McClean, John Robinson, 23 Great George Street, Westminster, S.W.
1860. McKenzie, James, Well House Foundry, Leeds.
1859. McKenzie, John, Vulcan Iron Works, Worcester.
1862. McPherson, Hugh, Engineer, Gloucester Gas Works, Gloucester.
1863. Meek, Sturges, Resident Engineer, Lancashire and Yorkshire Railway, Manchester.
1858. Meik, Thomas, Engineer to the River Wear Commissioners, Sunderland.
1857. Menelaus, William, Dowlais Iron Works, Merthyr Tydvil.
1857. Metford, William Ellis, Flook House, Taunton.
1847. Middleton, William, Vulcan Iron Foundry, Summer Lane, Birmingham.
1862. Miers, Francis C., Stoneleigh Lodge, Grove Road, Clapham Park, London, S.
1853. Miller, George Mackey, Great Southern and Western Railway, Dublin.
1862. Millward, John, Union Chambers, High Street, Stourbridge.
1856. Mitchell, Charles, Iron Ship Building Yard, Low Walker, Newcastle-on-Tyne.
1858. Mitchell, James, 3 Church Terrace, Higher Tranmere, Cheshire.
1861. Mitchell, Joseph, Worsbrough Dale Colliery, near Barnsley.
1859. Moor, William, Engineer, Hetton Colliery, Hetton, near Fence Houses.
1849. Morrison, Robert, Ouseburn Engine Works, Newcastle-on-Tyne.
1858. Mountain, Charles George, Suffolk Works, Berkley Street, Birmingham.
1863. Muir, William, Britannia Works, Manchester.
1857. Muntz, George Frederick, French Walls, near Birmingham.

1859. Murphy, James, Railway Works, Newport, Monmouthshire.
1858. Murray, Thomas H., Engine Works, Chester-le-Street, near Fence Houses.
1863. Musgrave, John, Jun., Globe Iron Works, Bolton.

1848. Napier, John, Vulcan Foundry, Glasgow.
1856. Napier, Robert, Vulcan Foundry, Glasgow.
1861. Natorp, Gustavus, Don Steel Works, Sheffield.
1861. Naylor, John William, Wellington Foundry, Leeds.
1858. Naylor, William, Great Indian Peninsula Railway, 3 New Broad Street, London, E.C.
1863. Neilson, Walter Montgomerie, Hyde Park Locomotive Works, Glasgow.
1860. Nettlefold, Joseph Henry, Screw Works, Broad Street, Birmingham.
1856. Newall, James, East Lancashire Railway, Carriage Department, Bury, Lancashire.
1862. Newton, William Edward, 66 Chancery Lane, London, W.C.
1858. Nichol, Peter Dale, Locomotive Superintendent, East Indian Railway, Allahabad, India: (or care of Anthony Nichol, 22 Quay, Newcastle-on-Tyne.)
1850. Norris, Richard Stuart, 272 Upper Parliament Street, Liverpool.

1860. Oastler, William, Engineer, Worcester Gas Works, Worcester.
1847. Owen, William, Messrs. Sandford and Owen, Phoenix Works, Rotherham.

1859. Paquin, Jean François, Locomotive Superintendent, Madrid Saragossa and Alicante Railways, Madrid, Spain.
1860. Parkin, John, Harvest Lane Steel Works, Sheffield.
1847. Peacock, Richard, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.
1848. Pearson, John, 1 Manchester Buildings, 7 Old Hall Street, Liverpool.
1859. Peet, Henry, London and North Western Railway, Locomotive Department, Wolverton.
1861. Perkins, Loftus, 3 Oberhafenstrasse, Hamburg: (or care of A. M. Perkins, 6 Francis Street, Regent's Square, London, W.C.)
1856. Perring, John Shae, 104 King Street, Manchester.
1863. Perry, Thomas J., Highfields Engine Works, Bilston.
1860. Peyton, Edward, Bordesley Works, Birmingham.
1856. Piggott, George, Birmingham Heath Boiler Works, Birmingham.
1854. Pilkington, Richard, Jun., 17 Tavistock Place, Tavistock Square, London, W.C.
1859. Pitts, Joseph, Old Foundry, Stanningley, near Leeds.
1859. Platt, John, Hartford Iron Works, Oldham.
1862. Player, John, Norton, near Stockton-on-Tees.

1861. Plum, Thomas William, 65 Cannon Street, London, E.C.
1856. Pollard, John, Midland Junction Foundry, Leeds.
1860. Ponsonby, Edward Vincent, Engineer, Great Western Railway, Worcester.
1852. Porter, John Henderson, Ebro Works, Tividale, near Tipton.
1861. Porter, Robert, Ebro Works, Tividale, near Tipton.
1856. Preston, Francis, Ancoats Bridge Works, Ardwick, Manchester.

1862. Rake, Alfred Stansfield, Royal Victoria Dockyard, Passage West, near Cork.
1847. Ramsbottom, John, Locomotive Superintendent, London and North Western Railway, Crewe.
1860. Ransome, Allen, Jun., Messrs. Worssam and Co., King's Road, Chelsea, London, S.W.
1862. Ransome, Robert James, Orwell Works, Ipswich.
1862. Ravenhill, John R., Glass House Fields, Ratcliff, London, E.
1859. Rennie, George Banks, 4 Prince's Terrace, Prince's Gate, London, S.W.
1862. Reynolds, Edward, Don Steel Works, Sheffield.
1863. Richards, Edwin, Pontypool Iron Works, Pontypool.
1856. Richards, Josiah, Abersychan Iron Works, Pontypool.
1863. Richardson, Edward, Engineer, Lyttelton, New Zealand.
1862. Richardson, Robert, 26 Great George Street, Westminster, S.W.
1858. Richardson, Thomas, Hartlepool Iron Works, Hartlepool.
1859. Richardson, William, Hartford Iron Works, Oldham.
1863. Rigby, Samuel, Cock Hedge Mill, Warrington.
1848. Robertson, Henry, Shrewsbury and Chester Railway, Shrewsbury.
1859. Robinson, John, Messrs. Sharp Stewart and Co., Atlas Works, Manchester.
1853. Ronayne, Joseph P., 4 Harbour Hill, Queenstown.
1856. Rouse, Frederick, Great Northern Railway, Locomotive Department, Leeds.
1857. Routledge, William, New Bridge Foundry, Adelphi Street, Salford, Manchester.
1860. Rumble, Thomas William, 6 Broad Street Buildings, New Broad Street, London, E.C.
1847. Russell, John Scott, 20 Great George Street, Westminster, S.W.
1863. Ryder, William, Bark Street, Bolton.

1859. Sacré, Charles, Locomotive Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.
1859. Salt, George, Saltaire, near Bradford, Yorkshire.
1848. Samuel, James, 26 Great George Street, Westminster, S.W.
1857. Samuelson, Alexander, 27 Cornhill, London, E.C.
1857. Samuelson, Martin, Scott Street Foundry, Hull.
1861. Sanderson, George Grant, Parkgate Iron Works, Rotherham.

1860. Schneider, Henry William, Ulverstone Hæmatite Iron Works, Barrow, near Ulverstone.

1858. Scott, Joseph, Messrs. R. & W. Hawthorn, Forth Banks, Newcastle-on-Tyne.

1861. Scott, Walter Henry, Mauritius Railways, Locomotive Department, Port Louis, Mauritius: (or Milton Road, Pewsey.)

1857. Selby, George Thomas, Smethwick Tube Works, Birmingham.

1850. Shanks, Andrew, 6 Robert Street, Adelphi, London, W.C.

1863. Sharp, Henry, Bolton Iron and Steel Works, Bolton.

1862. Sharpe, William John, 1 Victoria Street, Westminster, S.W.

1856. Shelley, Charles Percy Bysshe, 21 Parliament Street, Westminster, S.W.

1861. Shepherd, John, Union Foundry, Hunslet Road, Leeds.

1859. Shuttleworth, Joseph, Stamp End Works, Lincoln.

1851. Siemens, Charles William, 3 Great George Street, Westminster, S.W.

1862. Siemens, Frederick, 13 Beaufort Road, Edgbaston, Birmingham.

1862. Silvester, John, Messrs. George Salter and Co., Spring Balance Works, Westbromwich.

1862. Simpson, William, Conservative Club, St. James' Street, London, S.W.

1847. Sinclair, Robert, Great Eastern Railway, Stratford, London, E.

1857. Sinclair, Robert Cooper, 19 Temple Street, Birmingham.

1859. Slater, Isaac, Gloucester Wagon Company, Gloucester.

1853. Slaughter, Edward, Avonside Iron Works, Bristol.

1859. Smith, Charles Frederic Stuart, Mining Engineer, Midland Road, Derby.

1854. Smith, George, Wellington Road, Dudley.

1860. Smith, Henry, Brierley Hill Iron Works, Brierley Hill.

1858. Smith, Isaac, 36 Lancaster Street, Birmingham.

1860. Smith, John, Brass Foundry, Traffic Street, Derby.

1857. Smith, Josiah Timmis, Ulverstone Hæmatite Iron Works, Barrow, near Ulverstone.

1859. Smith, Matthew, Caledonia Wire Mills, Halifax.

1860. Smith, Richard, The Priory, Dudley.

1857. Smith, William, 19 Salisbury Street, Adelphi, London, W.C.

1863. Smith, William Ford, Gresley Iron Works, Ordsal Lane, Salford, Manchester.

1857. Snowdon, Thomas, 147 High Street, Stockton-on-Tees.

1859. Sokoloff, Capt. Alexander, Engineer, Russian Imperial Service, Steam Marine Department, Cronstadt, Russia: (or care of Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.)

1863. Somerville, Wallace Cochrane, Spon Lane Iron Foundry, Westbromwich.

1858. Sörensen, Bergerius, Engineer-in-Chief, Royal Norwegian Navy Department, Horten Dockyard, Norway: (or care of Messrs. Tottie and Sons, 2 Alderman's Walk, Bishopsgate Street, London, E.C.)

1859. Spencer, John Frederick, 3 St. Nicholas Buildings, Newcastle-on-Tyne.

1853. Spencer, Thomas, Old Park Works, near Shiffnal.

1854. Spencer, Thomas, Newburn Steel Works, Newcastle-on-Tyne.

1862. Stableford, William, Oldbury Carriage Works, near Birmingham.

1859. Stewart, Charles P., Messrs. Sharp Stewart and Co., Atlas Works, Manchester.

1851. Stewart, John, Blackwall Iron Works, Russell Street, Blackwall, London, E.

1857. Stokes, Lingard, 36 Carey Street, Lincoln's Inn Fields, London, W.C.

1863. Storey, John Henry, Knott Mill Brass and Copper Works, Little Peter Street, Manchester.

1862. Strong, Joseph F., Resident Engineer, East Indian Railway, Cawnpore, India.

1861. Sumner, William, 21 Clarence Street, Manchester.

1860. Swindell, James Evers, Parkhead Iron Works, Dudley.

1859. Swingler, Thomas, Victoria Foundry, Litchurch, near Derby.

1861. Tangye, James, Cornwall Works, Clement Street, Birmingham.

1859. Tannett, Thomas, Victoria Foundry, Leeds.

1861. Taylor, George, Clarence Iron Works, Leeds.

1858. Taylor, James, Britannia Engine Works, Cleveland Street, Birkenhead.

1862. Taylor, John, Mining Engineer, 6 Queen Street Place, Upper Thames Street, London, E.C.

1862. Taylor, Richard, Mining Engineer, 6 Queen Street Place, Upper Thames Street, London, E.C.

1857. Thompson, John Taylor, Messrs. R. and W. Hawthorn, Forth Banks, Newcastle-on-Tyne.

1857. Thompson, Robert, Haigh Foundry, near Wigan.

1862. Thompson, William, Spring Gardens Engine Works, Newcastle-on-Tyne.

1852. Thomson, George, Crookhay Iron Works, Westbromwich.

1861. Thwaites, Robinson, Vulcan Iron Works, Thornton Road, Bradford, Yorkshire.

1862. Tijou, William, 2 Dartmouth Street, Westminster, S.W.

1861. Tipping, Isaac, H. M. Gun Carriage Manufactory, Madras, India: (or care of H. Tipping, Bridgewater Foundry, Patricroft, near Manchester.)

1862. Tolmé, Julian Horn, 19 Duke Street, Westminster, S.W.

1863. Tomlinson, Edward, Miles Platting Works, Elm Street, Manchester.

1857. Tomlinson, Joseph, Jun., Locomotive Superintendent, Taff Vale Railway, Cardiff.

1856. Tosh, George, Locomotive Superintendent, Maryport and Carlisle Railway, Maryport.

1860. Townsend, Thomas C., 16 Talbot Chambers, Shrewsbury.

1863. Townsend, William, West Orchard, Coventry.

1862. Troward, Charles, Great Northern Railway, Locomotive Department, Doncaster.
1856. Truss, Thomas, Shrewsbury and Chester Railway, Carriage Department, Chester.
1859. Turner, Edwin, Bowling Iron Works, near Bradford, Yorkshire.
1856. Tyler, Capt. Henry Wheetley, R.E., Railway Department, Board of Trade, Whitehall, London, S.W.

1862. Upward, Alfred, Engineer, Chartered Gas Company, 146 Goswell Street, London, E.C.

1862. Vavasseur, Josiah, 28 Gravel Lane, Southwark, London, S.E.
1856. Vernon, John, Iron Ship Building Yard, Brunswick Dock. Liverpool.
1861. Vickers, Thomas Edward, Don Steel Works, Sheffield.

1856. Waddington, John, New Dock Iron Works, Leeds.
1856. Waddington, Thomas, New Dock Iron Works, Leeds.
1863. Wakefield, John, Great Southern and Western Railway, Locomotive Department, Dublin.
1861. Walker, John G., Netherton Iron Works, near Dudley.
1847. Walker, Thomas, Patent Shaft Works, Wednesbury.
1863. Walker, William Hugill, Wicker Iron Works, Sheffield.
1863. Wallace, William, Superintending Engineer, Montreal Ocean Steam Ship Company, Liverpool.
1856. Wardle, Charles Wetherell, Boyne Engine Works, Hunslet, Leeds.
1852. Warham, John R., Iron Works, Burton-on-Trent.
1862. Watkins, Richard, Canal Iron Works, Millwall, London, E.
1862. Webb, Francis William, London and North Western Railway, Locomotive Department, Crewe.
1862. Webb, Henry Arthur, Bretwell Hall Iron Works, near Stourbridge.
1860. Weild, William, Queen's Chambers, Market Street, Manchester.
1862. Wells, Charles, Moxley Iron Works, near Bilston.
1862. Westmacott, Percy G. B., Elswick Engine Works, Newcastle-on-Tyne.
1856. Wheeldon, Frederick R., Highfields Engine Works, Bilston.
1859. Whitham, James, Perseverance Iron Works, Kirkstall Road, Leeds.
1859. Whitham, Joseph, Perseverance Iron Works, Kirkstall Road, Leeds.
1863. Whitley, Joseph, New British Iron Works, Corngreaves, near Birmingham.
1847. Whitworth, Joseph, Chorlton Street, Manchester.
1852. Whytehead, William Keld, Engineer-in-Chief to the Government of Paraguay: 32 Cambridge Street, Eccleston Square, London, S.W.
1859. Wickham, Henry Wickham, M.P., Low Moor Iron Works, near Bradford, Yorkshire.

1859. Wickham, Lamplugh Wickham, Low Moor Iron Works, near Bradford, Yorkshire.
1847. Williams, Richard, Patent Shaft Works, Wednesbury.
1859. Williams, Richard Price, Stocksbridge Iron Works, Deepcar, near Sheffield.
1856. Wilson, Edward, Great Western Railway, Worcester.
1859. Wilson, George, Cyclops Steel Works, Sheffield.
1863. Wilson, John Charles, East India House, 5 Lime Street, London, E.C.
1852. Wilson, Joseph W., 9 Buckingham Street, Strand, London, W.C.
1857. Wilson, Robert, Bridgewater Foundry, Patricroft, near Manchester.
1860. Wilson, William, 3 Queen Square, Westminster, S.W.
1862. Winby, William Edward, Atherstone.
1859. Winter, Thomas Bradbury, 28 Moorgate Street, London, E.C.
1863. Wise, Francis, Chandos Chambers, Buckingham Street, Adelphi, London, W.C.
1858. Wood, Nicholas, Hetton Hall, Hetton, near Fence Houses.
1848. Woodhouse, Henry, London and North Western Railway, Stafford.
1851. Woodhouse, John Thomas, Midland Road, Derby.
1861. Woodhouse, William Henry, 11 Great George Street, Westminster, S.W.
1858. Woods, Hamilton, Messrs. Allsopp and Sons, Burton-on-Trent.
1860. Worssam, Samuel William, King's Road, Chelsea, London, S.W.
1860. Worthington, Samuel Barton, Engineer, London and North Western Railway, Manchester.
1859. Wright, Joseph, Metropolitan Carriage and Wagon Company, Saltley Works, Birmingham.
1860. Wright, Joseph, Neptune Forge, Tipton Green, Dudley.
1863. Wright, Owen, Broadwell Forge, Oldbury, near Birmingham.
1863. Wright, Peter, Railway Wheel Vice and Anchor Works, Dudley.
1853. Wymer, Francis W., Tyne and Continental Steam Navigation Company, Newcastle-on-Tyne.

1861. Yule, William, Baird's Works, St. Petersburg, Russia.

HONORARY MEMBERS.

1848. Branson, George, Belmont Row, Birmingham.
1863. Brockbank, William, 37 Princess Street, Manchester.
1863. Butler, William, 15 Bilbao Street, Cadiz, Spain.
1851. Clare, Thomas Deykin, Carr's Lane, Birmingham.
1848. Crosby, Samuel, Leek Street, Birmingham.
1863. Fairbairn, John, Farnley Iron Works, Leeds.
1863. Fisher, John, Priory Street, Dudley.
1863. Forster, George Emmerson, Washington, Durham.

1863. **Hackney**, William, 13 Beaufort Road, Edgbaston, Birmingham.
1860. **Hutchinson**, William, Blue Lias Lime Stone Offices, Lyme Regis.
1858. **Lawton**, Benjamin C., 3 St. Nicholas Buildings, Newcastle-on-Tyne.
1859. **Leather**, John Towlerton, Leventhorpe Hall, near Leeds. (*Life Member.*)
1860. **Manby**, Cordy, New Street, Dudley.
1863. **Nichols**, William, Midland Copper Works, Guild Street, Burton-on-Trent.
1856. **Pettifor**, Joseph, Midland Railway, Derby.
1861. **Ratcliff**, Charles, Wyddrington, Edgbaston, Birmingham.
1863. **Rigg**, Arthur, The College, Chester.
1859. **Sherriff**, Alexander Clunes, Great Western Railway, Worcester.
1863. **Storey**, Thomas R., 17 Gracechurch Street, London, E.C.
1848. **Warden**, William Marston, Edgbaston Street, Birmingham.
1858. **Waterhouse**, Thomas, Claremont Place, Sheffield.
1862. **Whitehead**, William, Don Steel Works, Sheffield.
1861. **Williamson**, Alexander W., Ph. D., University College, Gower Street, London, W.C.
1863. **Woolley**, John, Marehay Colliery, Ripley, near Derby.

GRADUATES.

1850. **Glydon**, George, Spring Hill Tube and Metal Works, Eyre Street, Birmingham.
1861. **Middleton**, Henry Charles, Vulcan Iron Foundry, Summer Lane, Birmingham.
1851. **Potts**, John Thorpe, 150 Camberwell Grove, London, S.

PROCEEDINGS.

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29 JANUARY, 1863.

The SIXTEENTH ANNUAL GENERAL MEETING of the Members was held at the house of the Institution, Newhall Street, Birmingham, on Thursday, 29th January, 1863; CHARLES F. BEYER, Esq., in the Chair.

The Minutes of the last General Meeting were read and confirmed.

The Secretary then read the following

ANNUAL REPORT OF THE COUNCIL.

1863.

The Council have much pleasure, on this the Sixteenth Anniversary of the Institution, in congratulating the Members on the very satisfactory progress and prosperous condition of the Institution.

The Financial statement of the affairs of the Institution for the year ending 31st December, 1862, shows a balance in the Treasurer's hands of £1781 17*s.* 11*d.* after the payment of the accounts due to that date. The Finance Committee have examined and checked the receipts and payments of the Institution for the last year 1862, and report that the following balance sheet rendered by the Treasurer is correct. (*See Balance Sheet appended.*)

The Council report with great satisfaction the continued increase in the number of Members that has taken place during the past year; the total number of Members of all classes for the year being 497, of whom 16 are Honorary Members, and 3 are Graduates.

The following deceases of Members of the Institution have occurred during the past year 1862 :—

William Hawkes, . . .	Birmingham.
William Weallens, . .	Newcastle-on-Tyne.
Francis Wrigley, . . .	Manchester.

The Council have the pleasure of acknowledging the following Donations to the Library of the Institution during the past year, and expressing their thanks to the Donors for the valuable and acceptable additions they have presented. The Council wish to urge on the attention of the Members the important advantage of obtaining a good collection of Engineering Books, Drawings, and Models in the Institution, for the purpose of reference by the Members personally or by correspondence ; and they trust this desirable object will be promoted by the Members generally, so that by their united aid it may be efficiently accomplished. Members are requested to present copies of their works to the Library of the Institution.

LIST OF DONATIONS TO THE LIBRARY.

Collection of Engineering Drawings, fifth part; from the Ecole Impériale des Ponts et Chaussées.

Description of the Models, Maps, and Drawings in the International Exhibition of 1862; from M. Cavalier.

Experiments on Wrought Iron and Steel, by David Kirkaldy; from the author.

On the Improvement of the Tyne, by Thomas John Taylor; from Mr. John Taylor.

The Archæology of the Coal Trade, by Thomas John Taylor; from Mr. John Taylor.

On the Resistance of Iron to Projectiles, by William Fairbairn; from the author.

On the Density of Steam, by W. J. Macquorn Rankine; from the author.

Description of an apparatus for Taking off the Waste Gas from Blast Furnaces, by E. Langen; from the author.

Philosophical Transactions and Proceedings of the Royal Society, 6 volumes; from Mr. Walter May.

Journal of the Architect and Engineer's Society for the kingdom of Hannover, from the commencement; from the Society.

Proceedings of the Institution of Civil Engineers; from the Institution.

Report of the British Association for the Advancement of Science; from the Association.

Proceedings of the Royal Institution of Great Britain; from the Institution.

Transactions of the North of England Institute of Mining Engineers; from the Institute.
Proceedings of the French Institution of Civil Engineers; from the Institution.
Journal of the Board of Arts and Manufactures for Upper Canada; from the Board.
Journal of the Royal United Service Institution; from the Institution.
Transactions of the Institution of Engineers in Scotland; from the Institution.
Proceedings of the South Wales Institute of Engineers; from the Institute.
Memoirs of the Literary and Philosophical Society of Manchester; from the Society.
Report of the Manchester Association for the Prevention of Steam Boiler Explosions; from Mr. Lavington E. Fletcher.
Transactions of the Royal Scottish Society of Arts; from the Society.
Report of the Royal Cornwall Polytechnic Society; from the Society.
Journal of the Society of Arts; from the Society.
The Engineer; from the Editor.
The Mechanics' Magazine; from the Editor.
The Civil Engineer and Architect's Journal; from the Editor.
The London Journal of Arts; from the Editor.
The Artizan Journal; from the Editor.
The Practical Mechanic's Journal; from the Editor.
The Mining Journal; from the Editor.
The Railway Record; from the Editor.
The Steam Shipping Journal; from the Editor.
Specimen Tube &c. from Hall's Surface Condenser; from Mr. T. Whittaker.

The Council have great satisfaction in referring to the number of Papers that have been brought before the meetings during the past year, and the practical value and interest of many of the communications and the discussions that took place upon them, which form a valuable addition to the proceedings of the Institution. The Council request the special attention of the Members to the importance of their aid and co-operation in carrying out the objects of the Institution and maintaining its advanced position, by contributing papers on Engineering subjects that have come under their observation, and communicating the particulars and results of executed works and practical experiments that may be serviceable and interesting to the Members; and they invite communications upon the subjects in the list appended, and other subjects advantageous to the Institution.

The following Papers have been read at the meetings during the last year:—

Address of the President, Sir William G. Armstrong.

On a Regenerative Gas Furnace, as applied to Glasshouses, Puddling, Heating, &c.; by Mr. C. William Siemens, of London.

On the Construction of Lighting Apparatus for Lighthouses; by Mr. Armand Masselin, of Birmingham.

On the Coal and Iron Mining of South Yorkshire; by Mr. Parkin Jeffcock, of Derby.

Description of a Feed-pipe Connexion for locomotive engines; by Mr. Alexander Allan, of Perth.

On Surface Condensation in Marine Engines; by Mr. Edward Humphrys, of Deptford.

On the application of the Copying principle in the Manufacture and Rifling of Guns; by Mr. John Anderson, of Woolwich.

On the relations of Power and Effect in Cornish Pumping Engines over long periods of working; by Mr. Charles Greaves, of Bow.

On the Manufacture of Hemp and Wire Rope; by Mr. Charles P. B. Shelley, of London.

On the Construction of Submarine Telegraph Cables; by Mr. Fleeming Jenkin, of London.

On the Double Cylinder Expansive Steam Engine; by Mr. William Pole, of London.

On Double Cylinder Pumping Engines; by Mr. David Thomson, of London.

On the Construction and Application of Iron Armour for Ships of War; by Mr. Norman S. Russell, of London.

On a Packing for Pistons of Steam Engines and Pumps; by Mr. George M. Miller, of Dublin.

On Machinery for the Manufacture of Gunstocks; by Mr. Thomas Greenwood, of Leeds.

Description of a Hydraulic Shears and Punch; by Mr. James Tangye, of Birmingham.

The Council have particular pleasure in referring to the great success and interest of the large and important Meeting of the Institution held in London last summer during the period of the International Exhibition, and in expressing their special thanks to the Local Committee and the Honorary Local Secretary, Mr. Charles Cubitt, for the excellent reception that was given to the Members of the Institution; and also to the authorities of the Government Works at Enfield and Woolwich for the valuable opportunity afforded to the Members for seeing those works on that occasion. The Council look forward with much confidence to the important advantages arising from the continuance of these Meetings in different parts of the country, from the facilities afforded by them for the personal communication of the Members in different districts of the country, and the opportunities of visiting the important Engineering Works that are so liberally thrown open to their inspection on those occasions.

The President, Vice-Presidents, and five of the Members of the Council in rotation, will go out of office this day, according to the rules of the Institution; and the ballot will be taken at the present annual meeting for the election of the Officers and Council for the ensuing year.

SUBJECTS FOR PAPERS.

STEAM ENGINE BOILERS, particulars of construction—form and extent of heating surface—relative value of radiant surface in effect and economy—cost—consumption of fuel—evaporation of water—pressure of steam—density and heat of steam—superheated steam, simple or mixed with common steam—pressure gauges—safety valves—water gauges—explosion of boilers, and means of prevention—effects of heat on the metal of boilers, low pressure and high pressure—steel boilers—incrustation of boilers, and means of prevention—evaporative power and economy of different kinds of fuel, coal, wood, charcoal, peat, patent coal, and coke—moveable grates, and smoke-consuming apparatus, facts to show the best plan, and results of working—plans for heating feed water—mode of feeding—circulation of water.

STEAM ENGINES—expansive force of steam, and best means of using it—power obtained by various plans—comparison of double and single cylinder engines—combined engines—compound cylinder engines—comparative advantages of direct-acting and beam engines—engines for manufacturing purposes—horizontal and vertical—condensing and non-condensing—injection and surface condensers—air pumps—governors—valves, bearings, &c.—improved expansion gear—indicator diagrams from engines, with details of useful effect, consumption of fuel, &c.—contributions of indicator diagrams for reference in the Institution.

Stamping and Coining Machinery, particulars of improvements, &c.

Paper-Making and Paper-Cutting Machines, new materials and results.

Printing Machines, particulars of improvements, &c.

Water Pumps, facts relating to the best construction, means of working, and application—velocity of piston—construction, lift, and area of valves.

Air Pumps, facts relating to the best construction, means of working, and application—velocity of piston—construction, lift, and area of valves.

Hydraulic Presses, facts relating to the best construction, means of working, and application—economical limit of pressure.

Rotary and Centrifugal Pumps, ditto ditto ditto

Fire Engines, hand and steam, ditto ditto ditto

Sluices and Sluice Cocks, worked by hand or hydraulic power, ditto

Cranes, steam cranes, hydraulic cranes, pneumatic cranes, travelling cranes.

Lifts for raising railway wagons—hoists for warehouses—safety apparatus.

Toothed Wheels, best construction and form of teeth—results of working—power transmitted—method of moulding—strength of iron and wood teeth.

Driving Belts and Straps, best make and material, leather, gutta percha, vulcanised india-rubber, rope, wire, chain, &c.—comparative durability, and results of working—power communicated by certain sizes—frictional gearing, construction and driving power obtained—friction clutches—shafting and couplings.

Dynamometers, construction, application, and results of working.

Decimal Measurement—application of decimal system of measurement to mechanical engineering work—drawing and construction of machinery, manufactures, &c.—construction of measuring instruments, gauges, &c.

Strength of Materials, facts relating to experiments, and general details of the proof of girders, &c.—girders of cast and wrought iron, particulars of different constructions, and experiments on them—rolled girders—best forms and proportions of girders for different purposes—best mixture of metal—mixtures of wrought iron with cast.

Durability of Timber of various kinds—best plans for seasoning and preserving timber and cordage—results of various processes—comparative durability of timber in different situations—experiments on actual strength of timber.

Corrosion of Metals by salt and fresh water, and by the atmosphere, &c.—facts relating to corrosion, and best means of prevention—means of keeping ships' bottoms clean—galvanic action, nature, and preventives.

Alloys of Metals, facts relating to different alloys.

Friction of Various Bodies, facts relating to friction under ordinary circumstances—facts on increase of friction by reduction of surface in contact—friction of iron, brass, copper, tin, wood, &c.—proportion of weight to rubbing surface—best forms of journals, and construction of axleboxes—

wood bearings—water axleboxes—lubrication, best materials, means of application, and results of practical trials—best plans for oil tests—friction breaks.

IRON ROOFS, particulars of construction for different purposes—durability in various climates and situations—comparative cost, weight, and durability—roofs for slips of cast iron, wrought iron, timber, &c.—best construction, form, and materials—details of large roofs, and cost.

FIRE-PROOF BUILDINGS, particulars of construction—most efficient plan—results of trials.

CHIMNEY STACKS of large size—particulars, form, mode of building, cheapest construction, &c.—force of draught, and temperature of current.

BRICKS, manufacture, durability, and strength—hollow bricks, fire bricks, and fire clay—perforated bricks, cost of manufacture, and advantages—dry clay bricks—machines for brick making—burning of bricks.

GAS WORKS, best form, size, and material for retorts—construction of retort ovens—quantity and quality of gas from different coals—oil gas, cheapest mode of making—water gas, &c.—improvements in purifiers, condensers, and gasholders—wet and dry gas meters—self-regulating meters—pressure of gas, gas exhauster—gas pipes, strength and durability, and construction of joints—proportionate diameter and length of gas mains, and velocity of the passage of gas—experiments on ditto, and on the friction of gas in mains, and loss of pressure.

WATER WORKS, facts relating to water works—application of power, and economy of working—proportionate diameter and length of pipes—experiments on the discharge of water from pipes, and friction through pipes—strength and durability of pipes, and construction of joints—penetration of frost in different climates—relative advantages of stand pipes and air vessels—water meters, construction and working.

WELL SINKING, AND ARTESIAN WELLS, facts relating to—boring tools, construction and mode of using.

TUNNELLING MACHINES, particulars of construction, and results of working.

COFFER DAMS AND PILING, facts relating to the construction—cast iron sheet piling.

PIERS, fixed and floating, and pontoons, ditto ditto

PILE DRIVING APPARATUS, particulars of improvements—use of steam power—particulars of working—weight of ram and height of fall, total number of blows required—vacuum piles—compressed air system—screw piles.

DREDGING MACHINES, particulars of improvements—application of dredging machines—power required and work done.

DIVING BELLS AND DIVING DRESSES, facts relating to the best construction.

LIGHTHOUSES, cast iron and wrought iron, ditto ditto

SHIPS, iron and wood—details of construction—lines, tonnage, cost per ton—water ballast.

MINING OPERATIONS, facts relating to mining—modes of working and proportionate yield—means of ventilating mines—use of ventilating machinery—safety lamps—lighting mines by gas—drainage of mines—sinking pits—mode of raising materials—safety guides—winding machinery—underground conveyance—mode of breaking, pulverising, and sifting various descriptions of ores.

BLASTING, facts relating to blasting under water, and blasting generally—use of gun-cotton, &c.—effects produced by large and small charges of powder—arrangement of charges.

BLAST FURNACES, consumption of fuel in different kinds—burden, make, and quality of metal—pressure of blast—horse power required—economy of working—improvements in manufacture of iron—comparative results of hot and cold blast—increased temperature of blast—construction and working of hot blast ovens—pyrometers—means and results of application of waste gas from close-topped and open-topped furnaces.

PUDDLING FURNACES, best forms and construction—worked with coal, charcoal, &c.—application of machinery to puddling.

HEATING FURNACES, best construction—consumption of fuel, and heat obtained.

CONVERTING FURNACES, construction of furnaces—manufacture of steel—casehardening, &c.—converting materials employed.

SMITHS' FORGES, best construction—size and material—power of blast—hot blast, &c.—construction of tuyeres.

SMITHS' FANS AND FANS generally, best construction, form of blades, &c.—facts relating to power employed and percentage of effect produced—pressure and quantity of air discharged—size and construction of air mains.

COKE AND CHARCOAL, particulars of the best mode of making, and construction of ovens, &c.—open coking—mixtures of coal slack and other materials—evaporative power of different varieties.

RAILWAYS, construction of permanent way—section of rails, and mode of manufacture—mode of testing rails—experiments on rails, deflection, deterioration, and comparative durability—material and form of sleepers, size, and distances—improvements in chairs, keys, and joint fastenings—permanent way for hot climates.

SWITCHES AND CROSSINGS, particulars of improvements, and results of working.

TURNTABLES, particulars of various constructions and improvements—engine turntables.

SIGNALS for stations and trains, and self-acting signals.

ELECTRIC TELEGRAPHS, improvements in construction and insulation—coating of wires—underground and submarine cables—mode of laying.

RAILWAY CARRIAGES AND WAGONS, details of construction—proportion of dead weight.

BREAKS for carriages and wagons, best construction—self-acting breaks—continuous breaks.

BUFFERS for carriages, &c., and station buffers—different constructions and materials.

COUPLINGS for carriages and wagons—safety couplings.

SPRINGS for carriages, &c.—buffing, bearing, and draw springs—range, and deflection per ton—particulars of different constructions and materials, and results of working.

RAILWAY WHEELS, wrought iron, cast iron, and wood—particulars of different constructions, and results of working—comparative expense and durability—wrought iron and steel tyres, comparative economy and results of working—mode of fixing tyres—manufacture of solid wrought iron wheels.

RAILWAY AXLES, best description, form, material, and mode of manufacture.

The communications should be written on foolscap paper, on one side only of each page, leaving a clear margin on the left side for binding, and they should be written in the third person. The drawings illustrating the paper should be on a large scale and strongly coloured, so as to be clearly visible to the meeting at the time of reading the paper; or enlarged diagrams should be added for the illustration of any particular portions: the scale of each drawing to be marked upon it.

INSTITUTION OF MECHANICAL ENGINEERS.

BALANCE SHEET.

For the year ending 31*st December*, 1862.

Cr.	£	s.	d.
By Balance 31st December, 1861	1420	9	5
„ Subscriptions from 34 Members in arrear	102	0	0
„ ditto from 441 Members for 1862	1823	0	0
„ ditto from 2 Graduates for 1862	4	0	0
„ ditto from 6 Members in advance for 1863	18	0	0
„ Entrance Fees from 62 New Members	124	0	0
„ Sale of Extra Reports	13	12	0
„ Interest from Bank	33	12	5
	£3038	13	10

Dr.				£	s.	d.
To Printing and Engraving Reports of Proceedings	462	7	1			
Less Authors' copies of papers, repaid	52	0	6	410	6	7
„ Stationery and Printing				71	1	8
„ Office Expenses and Petty Disbursements				69	7	9
„ Expenses of Meetings				27	11	8
„ Fittings and Repairs				9	1	8
„ Travelling Expenses				28	18	0
„ Parcels				3	19	2
„ Postages				50	0	4
„ Salaries				450	0	0
„ Rent and Taxes				119	12	6
„ Coals, Gas, and Water				16	16	7
Balance 31st December, 1862				1781	17	11
				£3038	13	10

(Signed) WALTER MAY, } Finance Committee.
EDWARD JONES, }

29th January, 1863.

MEMOIRS

OF MEMBERS DECEASED IN 1862.

William Hawkes was born at Moseley near Birmingham in 1800; and after serving his time with Mr. William Brunton at the Eagle Foundry, Broad Street, Birmingham, became a member of the firm of Messrs. Smith and Hawkes at the same works, in which he continued an active partner up to nearly the time of his death. His health having been declining for more than two years previously, he died on 31st May 1862 at the age of sixty-two. He was elected an Honorary Member of the Institution in 1857.

William Weallens was born on 8th March 1823 at Ponteland near Newcastle-on-Tyne, and was educated at the Grange School, Bishopwearmouth. He acquired his knowledge of mechanical engineering at Messrs. Robert Stephenson and Co.'s works at Newcastle-on-Tyne, where he first became a pupil in 1838, and afterwards succeeded his father-in-law, Mr. William Hutchinson, as resident partner in the firm. He gained considerable reputation as a sound practical mechanic, and was much esteemed by numerous friends and acquaintances for his kindness and geniality of disposition. He was a Member of the Institution from its commencement in 1847, and was for several years a member of the Council. He died at Paris on 2nd Nov. 1862 in the fortieth year of his age, having been taken ill whilst on a journey.

Francis Wrigley was born at Manchester in 1811, and was for some time actively engaged with the firm of Messrs. Sharp Roberts and Co. of that town. In 1841 he went to Russia, and was engaged in the erection of machinery at various cotton and sugar works in that country. He returned to England in 1857, and during the last two years was partner in the firm of Messrs. Fothergill Wrigley and Smith, consulting engineers, Manchester. He became a Member of the Institution in 1859, and died on 2nd Aug. 1862 after an illness of only a few days' duration.

The **Chairman** remarked that the very prosperous condition of the Institution and the continued increase in the number of the Members seen from the Report of the Council were highly satisfactory and encouraging, and showed the extended utility of the Institution: he moved that the Report be received and adopted, which was passed.

In accordance with the notice given at the last General Meeting, the following resolution was moved by the Chairman and was passed:— "That all Members who have filled the office of President of the Institution be ex officio permanent Members of Council, under the title of Past Presidents."

The **Chairman** announced that the Ballot Lists had been opened by the Committee appointed for the purpose, and the following Officers and Members of Council were duly elected for the ensuing year:—

PRESIDENT.

Robert Napier, ...	Glasgow.

PAST PRESIDENTS.

Ex officio permanent Members of Council.

Sir William G. Armstrong, .	Newcastle-on-Tyne.
James Kennedy, . . .	Liverpool.
John Penn, ...	London.
Joseph Whitworth, . .	Manchester.

VICE-PRESIDENTS.

Charles F. Beyer, . . .	Manchester.
Alexander B. Cochrane, .	Dudley.
Edward A. Cowper, . . .	London.
James Fenton, . . .	Low Moor.
Henry Maudslay, . . .	London.
John Ramsbottom, . . .	Crewe.

COUNCIL.

Daniel K. Clark, . . .	London.
William Clay, . . .	Liverpool.
John Fernie, ...	Derby.
Sir Charles Fox, . . .	London.
Edward Humphrys, . . .	London.
James Kitson, . . .	Leeds.
Sampson Lloyd, ...	Wednesbury.

Members of Council remaining in office.

Alexander Allan,	Perth.
John Anderson,	Woolwich.
George Harrison,	Birkenhead.
Thomas Hawksley,	London.
Robert Hawthorn,	Newcastle-on-Tyne.
Edward Jones,	Wednesbury.
Walter May,	Birmingham.
Charles P. Stewart,	Manchester.

TREASURER.

Henry Edmunds,	Birmingham.

SECRETARY.

William P. Marshall,	Birmingham.

The following New Members were also elected:—

MEMBERS.

Henry Brown,	Birmingham.
James Kennan,	Dublin.
Thomas Knight,	Birmingham.
Ernest Latham,	London.
Edward Richardson,	New Zealand.
Thomas Wicksteed,	London.

The following paper was then read:—

ON THE APPARATUS USED FOR SINKING PIERS FOR IRON RAILWAY BRIDGES IN INDIA.

BY MR. JOSEPH F. STRONG, OF ALLAHABAD.

The general mode adopted for forming the foundations for railway bridges over the large Indian rivers is an application of the old native plan of sinking cylinders or wells of brickwork, by excavating the sand from the interior of the cylinders and allowing them to sink by their own weight, increasing the height of each cylinder successively by additional brickwork until it has sunk to a sufficient depth to obtain the required hold in the ground. This plan has been in use for ages in that country for forming the foundations of the native forts on the banks of rivers, and also for sinking wells for water. In the case of the railway bridges the same plan is extended, by being carried out upon a larger scale to obtain a greater depth and consequently greater stability of foundation: sets of brick cylinders, varying in number from three to twelve and in diameter from 18 to 8 feet, based upon wrought iron or wood curbs, are sunk to a sufficient depth in the ground to form the foundations for each pier.

The bridge of which the foundations are described in the present paper is on the main line of the East Indian Railway from Calcutta to Delhi, and spans the river Jumna at Allahabad, about 1¼ mile above its confluence with the Ganges. It is composed of 14 openings of 205 feet clear span each, crossed by wrought iron girders, and giving a total waterway of 2875 feet, the distance between the abutments being 3075 feet; the height of the top of the piers is 58 feet 6 inches and of the rails 80 feet above low water level. Fig. 1, Plate 1, is a general elevation of half the length of the Jumna bridge, and Fig. 2 a transverse section: Fig. 3 gives a section of the bed of the river, the vertical scale being enlarged five times. For the foundations of the bridge ten brick cylinders A A of 13 feet 6 inches diameter are employed in each pier, sunk to a depth of 43 feet below the low water level, as shown in Fig. 4, Plate 2, which is an elevation of one of the piers taken transversely of the bridge. Fig. 6, Plate 3, is a corresponding sectional plan of the pier, one half being taken through the brick cylinders A A, and the other half through the masonry above them, the outline of the pier being shown by the strong dotted line. Fig. 5 is a vertical section of the pier to a larger scale, taken longitudinally of the bridge, showing a section of a pair of the brick cylinders.

The Jumna, like most of the Indian rivers, winds about much in its course, and varies in width and depth considerably; and within a distance of three quarters of a mile above and below the railway bridge it is 65 and 72 feet deep respectively at low water; but this depth is reduced to only 15 feet at the spot selected for crossing by the chief engineer, Mr. Edward Purser. A number of experimental brick cylinders were sunk to ascertain what the bed of the river consisted of, and at a depth of 35 feet nothing but sand partly mixed with clay was found. Generally speaking the water is so low in the Indian rivers between the months of November and May that there are no great difficulties to be got over in beginning operations for sinking the cylinders to form the foundations of the piers: but in the Jumna, which is never dry, it was unavoidable that the piers had to be begun where there was deep water; and as the means of pitching iron curbs under water were not at hand, the question arose what was the best mode of commencing the building of the cylinders preparatory to sinking them.

The simplest plan seemed to be to form an artificial island for each pier; and this was done in the following manner. Taking the centre of a pier in 15 feet depth of water as the starting point, and setting out a space of 175 feet length by 120 feet width, sand bags were sunk on the down stream and two adjacent sides, thus forming three sides of an enclosure, in the centre of which loose sand was thrown, which was carried by the stream and deposited against the upper side of the lower boundary of sand bags, where it formed a ridge; in due course the surface of the water was thus reached, when the sand was all thrown on the up stream side, and an island was thereby speedily formed 100 feet long by 60 feet wide at the top. On this island the ten iron curbs were pitched to form the bases for the ten brick cylinders composing the foundations of the pier, being pitched at a distance of 15 feet 6 inches centre to centre transversely of the pier, and 15 feet longitudinally.

The iron curb is shown enlarged in Fig. 7, Plate 4, which gives a vertical section of one of the brick cylinders to a larger scale, showing the cylinder A A partially sunk. The curb B is 13 feet 6 inches diameter outside and 8 feet 6 inches inside, the interior of the brick cylinder diminishing to 6 feet 9 inches diameter. The curb consists of a flat horizontal ring of ⅜ inch boiler plate, 2 feet 6 inches wide, rivetted by an angle iron to an outer cylindrical ring of similar plate 18 inches deep, and having gusset plates connecting the two rings underneath. The outer cylindrical ring extends 3 inches above the horizontal one, forming a support all round to the base of the brick cylinder on the outside; and an angle iron upon the inner edge of the flat ring forms a similar support within. To keep the curbs in place they are sunk till the top plate of the curb is bedded on the sand; then 12 feet height of brickwork 3 feet 4½ inches thick is built upon the curb, the first 5 feet of which is sunk by simply taking out the sand from the underside of the curb by hand; after which another and quite a different plan of sinking has to be adopted.

The implement generally used for getting out sand &c. in deep foundations in India is called a "jham;" it has been known and used by the natives for ages in sinking wells for water, and also wells for foundations of river forts, quay walls, &c. The jham is a large scoop, something in the form of a large hoe with a short handle, which the natives invariably make of wood, simply having the cutting edge shod with iron. The plan of working they adopted was to send down divers into the water in the interior of the brick cylinder, who with the jham loosened the sand or clay at the bottom; then the diver filled the jham with the loose materials, and was hauled up with it out of the water. This implement was in fact never employed by the natives without the aid of divers who did the excavating work with the jham itself; they are expert in the use of it, remaining under water regularly about a minute each time of diving. Even in foundations for road bridges built under the direction of government engineers, the jham has been used only in conjunction with divers; and also on the Madras railway, as has been elsewhere described by the chief engineer, Mr. G. B. Bruce, the same means were employed in sinking the brick cylinders for the foundations of the river bridges; the rivers being in that case comparatively small and shallow, and quite dry in the working season.

It is evident that a stronger and more efficient apparatus was needed to sink cylinders 43 feet deep below the water level, through dense sand, as in the case of the large Jumna bridge; and the results of numerous trials with many kinds and forms of the tool gave a jham such as is shown at C in Fig. 7, Plate 4, and Fig. 10, Plate 5. This jham is made of wrought iron with a scoop 2 feet 2 inches wide and 2 feet 4 inches long, made thin and sharp at the front edge, and supported by two stays fixed to the sides of the scoop and also made thin and sharp at their front edges for penetrating the ground readily; the whole weighing about ¾ cwt.

The mode of using this jham is as follows. By means of a couple of ropes D attached to the tail end of the arm E, the jham is lowered by hand to the bottom of the well, till the cutting edge of the scoop C and the outer end of the arm E rest upon the sand, as shown by the full lines in Fig. 7, Plate 4. Then with the weight of two or three men bearing on the top of the vertical pole F, which is held in place by the pin at the bottom passing loosely through a hole in the tail end of the arm E, the scoop is raised a short distance by the ropes D, the outer end of the arm resting upon the sand and forming a sort of centre of motion; and the scoop is then dropped with the weight of the men bearing upon it, and its cutting edge is thus forced into the sand. By repeating these strokes the scoop is forced into the position shown in Fig. 8, Plate 5, the workmen knowing by the feel when the scoop is deep enough in the sand. Then with the weight of the men still on the vertical pole F, the jham is hauled up by means of the windlass G, round the barrel of which the chain is wound that is attached to the extremity of the arm E; the jham being thereby tilted into the position shown in Fig. 9, and brought up filled with sand as shown dotted in Fig. 7, Plate 4. It requires ten men at the windlass to move the jham when bedded in the sand in the position shown in Fig. 8, and lift it to the position shown in Fig. 9; it is then drawn up to the top, emptied, and the process repeated.

After the first length of 12 feet of brick cylinder has been sunk down to the water level, an additional 15 feet is added, as shown in Fig. 5, Plate 3; and the process of sinking continues till the 15 feet added has been sunk, when an additional 16 feet is added, making a total of 43 feet depth. As a precaution for preventing the curb and lower portion of the brick cylinder from parting from the upper portion, in consequence of the latter being held by the friction of the sand being greater at that part, which is found sometimes to occur, provision is made on the curb for attaching six holding up bolts, which are built into the brickwork for a length of 16 feet, as shown in Fig. 5, Plate 3, and at intervals of every 5 feet a ring of flat iron is dropped over all the bolts and cottered down on to the brickwork.

The rate of sinking of the cylinders is far from regular; at starting the progress is pretty even, the cylinders going down from 15 to 9 inches per day; but the average rate of sinking when down to 20 feet is not more than 4½ inches per day; and beyond that depth the rate of progress gradually decreases till it is not more than 1½ to 1 inch per day of 24 hours. The plan that is adopted where the sinking goes on slowly is to add extra weight on the top of the cylinder, either by building extra brickwork or adding a load of rails. In very bad cases both means are used, till a weight of 40 tons on each cylinder has been added; and even with this additional load on the top great difficulty has been met with when the sinking has reached a depth of 40 feet; which is not surprising when it is considered that there is then a constant pressure due to 40 feet head of water acting upon the sand round the exterior surface of the cylinder at the bottom.

When the cylinders have been got down to the depth of 43 feet they are ready for the concrete H, Fig. 5, Plate 3; but before throwing in the concrete, a diver supplied with Siebe's diving apparatus is sent down to clear away any rubbish that may be left at the bottom of the well, and level the space under the curbs for the reception of the concrete. A depth of 15 feet of concrete is then thrown in, composed of 1 part of fresh-burnt unslaked lime, 1 of broken bricks, and 2 of underburnt lime; these are the usual proportions of the concrete used in stopping the cylinders, and about 18 days are generally allowed for it to set. A disc made of two thicknesses of 2 inch planking is let down upon the surface of the concrete, weighted by 3 feet thickness of brickwork; this disc is a little less in diameter than the inside of the cylinder, so as to pass freely down on to the concrete, the space between the edge of the disc and the sides of the cylinder being then filled in with wood wedges driven by divers. The object of putting in this disc is to prevent the concrete being disturbed by the pressure of water underneath, whilst the water is being baled out from above the concrete, preparatory to building the cylinder up solid.

The lime used in India is peculiar, and is called "khunkur." It is picked up in the beds of rivers and small streams after the rains, and is found sometimes in isolated beds; but generally it is in detached masses composed of pieces of about the size that stone is broken for metalling roads. It is of a light grey colour, and is burnt in the usual way, either in heaps or in kilns, the latter being preferred; and the percentage obtained is generally about 55 per cent. The mortar used is generally made of 1 part of lime to 1 or 1½ parts of "soorkhee," which consists of bricks pounded and passed through a sieve of 8 meshes to the inch; this mortar is of the best description, being hydraulic, and setting almost better in water than out of it. No sand is found in India sufficiently sharp for making mortar; hence the use by the natives in the first instance, and now by Europeans, of brick-dust, as it may be called, in place of sand for making mortar.

The next operation after having made tight the wood disc upon the top of the concrete is to bale out the water and build up the void inside the cylinder solid with rubble stone, as shown in Fig. 5, Plate 3; this is carried up to the top of the cylinders, and their tops are thus reduced to an even bed ready for the covering stones. As a precaution to prevent these stones from spreading, a groove is cut in the top of the cylinders 6 inches deep and extending lengthways of the pier, as seen in Fig. 4, Plate 2; into this groove the large stones are laid, and they stretch across the space between the cylinders, and have a good hold on each cylinder. The stones are all cramped at the joints with 1¼ inch square iron, and the stones in the next course above are dropped into joggles in the first course. The hearting of the cylinders is then carried up in brickwork, diminishing by a set-off of 2¼ inches at each course to form a core or centre for the corbelling or over-sailing of the brick steining of the cylinders. A similar provision is made on the outside of the cylinders by throwing in concrete between the cylinders, and building concentric rings of brickwork upon that: over these the corbelling on the outside of the cylinders is carried. There are twelve courses of brickwork between the top of the cylinders and the top of the second course of the covering stones; and at this level there is a through or bonding course of ashlar, running transversely to the piers, as shown in Fig. 5, Plate 3. Up to the top of the plinth there are similar courses faced only with ashlar, the backing or hearting being large rubble. The piers between the plinth and cap are built with ashlar facing to the cutwaters, blocking courses between the shoulders of the cutwaters, and rubble backing behind throughout the whole length of the piers. There are large stones for carrying the cast iron bed plates, upon which the saddles supporting the end standards of the bridge rest.

Fig. 4, Plate 2, shows a complete elevation of one of the piers taken transversely of the bridge, with one of the girders in position and the second one dotted; only one line of rails being at present in process of construction, though all the piers and abutments are made complete for a double line of rails. The general elevation of one half of the complete bridge, shown in Fig. 1, Plate 1, contains seven openings in the half length, of 205 feet clear span each. The girders are wrought iron trusses designed by Mr. George Rendel, in principle something like a double Warren truss, the railway being carried upon the top, and a public roadway upon the bottom of the girders. The girders are constructed with a rectangular box at the top and flat tension bars at bottom; the vertical struts are plain bars with double angle irons, and are clipped between the transverse flanges of the top box; the diagonal ties are flat bars. In the construction of the girders all the holes are drilled, none being punched. The weight of the pair of girders for one span is for the length of 210 feet between the supports 288 tons, including the cross girders but exclusive of the covering of the roadway and railway; being a weight of 27½ cwts. per foot run.

The section of the river bed, Fig. 3, Plate 1, shows the body of water in the river at low water, and the lower dotted line shows the ordinary rise of the river at flood time, being about 45 feet rise: the level of the underside of the girders is fixed at 14 feet above the ordinary flood level. The upper dotted line shows the extraordinary rise of 51½ feet that took place in the years 1838 and 1861. During the time of the last extraordinary flood of 1861 the current of the river increased to the rate of 9 miles an hour, the ordinary rate when not flooded being only 2 to 3 miles an hour.

Mr. Strong exhibited a model of one of the brick cylinders for forming the bridge piers, showing the construction of the wrought iron curb and the mode of building the brickwork upon it; and also a model of the scoop and windlass used in excavating within the cylinders.

The Chairman asked for some particulars of the materials through which the foundations had to be sunk.

Mr. Strong said that the material to be sunk through was generally sand, but occasionally beds of lime and clay were met with, which however were never either hard or very thick. This process of sinking was not suited for getting through anything much harder than ordinary sand; consequently when lime or stone boulders were met with in sinking it was necessary to send divers down to break up the layer of hard material, so that the pieces could be got up by means of the scoop. When the cylinders had been got down to a depth of 40 feet, the friction produced by the pressure of the sand on the outer surface of the cylinder was so great and the sand below was so hard that the further progress of the sinking was necessarily slow. Other modes of making foundations in sand had been tried, but the plan now described was the only means that he knew of which had been successfully adopted for sinking brick foundations to any great depth in sand; and he believed the East Indian Railway was the only line upon which the bridge foundations had been sunk in that manner. Iron cylinders, such as had been used for piers in England, were not to be had in India, and the plan adopted appeared to be the only one available under the circumstances.

Mr. H. W. **Harman** thought the plan of sinking described in the paper appeared quite suitable for sinking foundations in sand; but he considered the apparatus employed would be inadequate for getting up any material of greater density, such as clay. He was at present engaged in some difficult operations of a similar character, in sinking iron cylinders for railway bridge piers in the bed of the Trent near Keadby, and great difficulty had been found in getting through the bed of the river, the interior of the cylinders being kept free of water by maintaining a sufficient pressure of air inside them, and the material excavated being brought up and transferred through the air cell at the top of the cylinder to the outside by hand labour: the process was the same as that employed at Rochester bridge, and was indeed the only one whereby the difficulties met with in such a river could be overcome. In the case of the Indian rivers, as described in the paper, he could easily understand that the sand could be got out very readily by the scoop employed for the purpose: but he was surprised to learn that the progress made was so slow as only 4½ inches depth sunk in 24 hours at a depth of 20 feet, which did not seem to be satisfactorily accounted for. He enquired whether any difficulty had been experienced in keeping the brick cylinders vertical during the sinking, and how that was effected; for if the building of the cylinders were kept up above the surface of the ground, they would be exposed in flood time to a tide running at 9 miles an hour, and in a rapid river great difficulty was found in sinking iron cylinders truly vertical, which would be still greater in the case of brick cylinders built up gradually.

Mr. **Strong** explained that in the Indian rivers the floods occurred only once a year, and the pier foundations were sunk in the intervening dry season. At ordinary low water the current ran at only 2½ miles an hour, and the cylinders stood up only 7 or 8 feet above the bottom of the river. The means adopted for keeping them vertical in sinking was to move the windlass round through a quarter of a circle every six hours, so as to take the sand with the scoop from every side successively of the interior of the cylinder. In taking the sand from the inside, some of the sand outside necessarily got forced in at the bottom of the cylinder by the external pressure, which had also to be got out by the scoop: and this, with the continually increasing density of the sand, was the reason why the rate of progress diminished so rapidly when the depth sunk was considerable.

Mr. H. **Woods** asked whether any other plan of getting up the sand had been tried, besides that described, in order to raise it more quickly. He had made about six years ago for Mr. Ward a set of machines like vertical dredgers, intended to be used on some of the railways in India for getting up the sand in sinking pier foundations, and he believed it was intended to use ten of the machines at a time. Each dredger had about thirty light wrought iron buckets, 12 or 15 inches long and the same breadth at the widest part, with the mouths steeled: there was an adjustment for sinking the dredger down to work to a depth of 30 feet, and the buckets delivered the sand into a moveable spout worked by a cam, which brought the spout forwards to receive the charge of each bucket as it came to the top, and then drew it back again out of the way to allow the empty bucket to pass down clear. He did not know however about the working of these machines.

Mr. **Strong** replied that the dredgers referred to had been used, but only to a depth of 10 or 12 feet. In shallow water they might be used advantageously, but at a greater depth the inclination was too steep for them to work well. The brick cylinders of 43 feet depth and 6 feet 9 inches inside diameter had so small space inside for the dredgers that the buckets had not room to deliver themselves in working at a great depth.

The **Chairman** enquired whether the layers of clay that were met with in sinking were hard enough to keep out the water.

Mr. **Strong** replied that the clay met with in sinking in such rivers as the Jumna was not hard like ordinary brick clay, but was nearly always mixed with sand, and consequently was not close enough to keep out water: there was also not sufficient depth of clay for the purpose. For more than half way down in the sinking, a great quantity of the sand outside the cylinders had to be taken out by the scoop, being forced up into the bottom of the cylinders by the external pressure, which rendered the progress of sinking so slow: but when down to about 30 feet depth something like fine gravel was met with, which was easier to work, although less was got out at each haul of the scoop; and this did not run in from the outside like the sand. With 35 to 40 feet head of water upon the sand it was almost as hard as stone, and there was great difficulty in forcing the scoop far enough into it to bring up a large quantity at one time: this did not however materially affect the progress of sinking. Down to a depth of 10 feet from the surface of the ground the rate of sinking was about 18 inches per day.

Mr. H. W. **Harman** asked what was the cost of sinking the brick cylinders by this plan, in order that there might be the means of comparing it with the cost of screw piles for foundations.

Mr. **Strong** said the cost of sinking each separate cylinder by this plan was 10*s*. per foot down to 5 feet depth; between 5 and 10 feet it was 20*s*. per foot, between 10 and 15 feet 30*s*. per foot, and so on, increasing regularly 10*s*. per foot at every additional 5 feet of depth, down to 40 feet depth, beyond which the rate was 90*s*. per foot. Those were the rates paid to the men for labour only, the materials being found for them. The work was all done by contract: one contractor undertook the sinking of one or more cylinders at those rates, and paid his own men.

Mr. H. W. **Harman** thought the cost of the sinking at that rate would be greater than by the use of screw piles. He enquired whether all the cylinders in one pier were sunk simultaneously, or whether they would interfere with one another if sunk together.

Mr. **Strong** replied that all the cylinders were sunk together in one pier, as it was easier and much quicker work to sink them all together.

Mr. J. **Fernie** asked what determined the depth to which the cylinders were to be sunk; and whether at the bottom of the deepest piers the material was still the same or was found to vary.

Mr. **Strong** replied that during the dry season, when the water was low, sections were taken across the rivers, and the depth of the river bed was never found to vary to any great extent, the average greatest depth at low water being about 15 feet: but the deepest part was seldom found in the same place two seasons running. The piers were generally sunk to a depth of about 43 feet below the low water level; and borings had been taken, but nothing but sand was found at a depth of 80 feet below the water level. Sometimes the sand had been found to be mixed with clay and loose stones, but nothing like rock was ever met with.

Mr. E. **Gilkes** enquired whether there had been any failure with the brick piers.

Mr. **Strong** said the only failure there had been occurred during the high floods of 1861, when the four up-stream cylinders out of the ten in one pier fell over. This was owing to the sand inside the cylinders having been scooped out in the process of sinking to as great a depth as 18 feet below the curbs, so that the cylinders were hanging as it were in their places, held up only by the friction of the sand outside. When the flood came down and the water began to eddy round the cylinders, the sand was set in motion and gradually loosened round them; and eventually, the support being taken away from them, they slipped down and in so doing quietly fell over on their sides. It was subsequently ascertained by probing with steel rods that the convex side of the cylinders was unbroken: they had simply fallen over, but had not broken to pieces.

Mr. F. J. **Bramwell** asked whether the fallen cylinders had been replaced yet, and whether they would not have to be removed for the purpose.

Mr. **Strong** said the cylinders had not been replaced when he left India last year: a cofferdam had already been made round the spot where they lay, and an excavation was being commenced for the purpose of getting down to them. When got at they would have to be broken up in order to be removed.

The **Chairman** enquired what sort of mortar the cylinders were built with.

Mr. **Strong** replied that the mortar used in building the cylinders was the best mortar he had ever met with, and was harder to break than the bricks themselves. The lime they obtained was of excellent quality for the purpose, and pounded brick instead of sand was employed for making the mortar, and was used everywhere throughout India in preference to sand, because the sand was too fine. He had known cases where brickwork had had to be broken up by blasting with gunpowder on account of the mortar being so strong.

Mr. F. J. **Bramwell** suggested that the cylinders might be sunk much more rapidly if they were weighted with an additional load for the purpose, as there appeared to be an objection to increasing the height of the cylinders in order to get a greater weight. If they could be made to go down quicker, he thought there would not be so much sand running in from the outside, which was the cause of the delay in sinking; and it would not be necessary to shift the scoop and windlass round several times during the day to make the cylinders go down straight. When the shaft of the Thames Tunnel on the Wapping side of the river was sunk, the brickwork was built up to a height of 25 feet on the iron curb before the excavation was commenced, in order to make it go down rapidly and steadily; and it was afterwards loaded two or three times during the sinking, to get it down.

Mr. H. W. **Harman** concurred in the desirability of loading the cylinders in order to sink them rapidly, so as to prevent the material outside from getting forced in at the bottom by the pressure of the water. He had found some difficulty with the iron cylinders of the Trent bridge that he had referred to, and had loaded them with 35 to 40 tons of railway rails: they then sank rapidly, and nothing had to be excavated except the material inside the cylinders, as none of that outside found its way in.

Mr. E. **Gilkes** remarked that he had also found in using screw piles that when the screw came to a place where it could not be sunk further, the addition of a heavy weight on the top of the pile would make the screw bite and enable the pile to be screwed down to the required depth.

Mr. E. A. Cowper thought that not only was weighting necessary to sink the cylinders rapidly enough, but a different form of iron curb was desirable at the bottom of the cylinder, to avoid having such a large flat surface at the bottom of the cylinder, which must oppose a great resistance to its easy descent. He suggested that if the outer edge of the iron curb were prolonged considerably in advance of the bottom of the brick cylinder, so as to present a cutting edge all round, the cylinder would then sink faster, because the projecting curb would reach so far down into the sand as to prevent the external sand from getting forced up into the bottom of the cylinder. In sinking pier foundations in sand or any other loose material, rapidity of sinking was indeed essential, in order to avoid raising an unnecessarily large quantity of material. In sinking hollow piles on Potts' plan, by making a vacuum inside the pile with an air pump and so sucking up the water, gravel, mud, or other material, he had found that, when there was sufficient exhausting power and the pipe communicating from the exhausted vessel to the pile was of sufficiently large area, the pile could be got down 5 feet at a suck in certain cases; but if the suction pipe were small and the exhausting were done gradually, the outside material got sucked in at the bottom of the pile, and the sinking was slow, besides which the material about the outside of the pile was loosened. Hence it was desirable to take out the material inside the pile rapidly, so as to allow as little as possible of the external material to be drawn in at the bottom. A simple apparatus had been used by Mr. Kennard for sinking pier foundations in light soils in Spain and Italy, consisting of a rough iron box 3 or 4 feet diameter and about 2½ feet high, with an open pipe at the top about 2 feet high and 9 inches diameter, in which a cannon ball of nearly the same diameter was suspended by a chain and worked up and down by hand, forming a rough sort of pump: at the bottom of the box was another open pipe of the same diameter, standing up 4 or 5 inches inside the box and projecting about 6 or 8 inches below. This sand box was lowered down to the bottom of the water, and the ball being jerked up and down by the chain, the mixed water and sand were drawn in through the open pipe at the bottom, and the sand fell over the top of the pipe into the box, while the water escaped through valves opening outwards in the top of the box. In this way a barrowful of sand was got into the box in a very few minutes.

The **Chairman** enquired whether any experiments had been made as to the resistance of the brick cylinders to sinking, and the weight required to sink them in the sand.

Mr. **Strong** replied that no experiments had been tried as to what weight it would take to sink the cylinders deeper in the sand after they had been sunk to their final depth; but they had tried an experiment as to the supporting power of sand under water, for some fear had been expressed at first that if the pier cylinders should ever be left partially unsupported, by the sand being scoured away from the sides, they would under the weight of the piers and superstructure sink deeper into the sand. To ascertain whether this would really be the case, the following experiment was tried. Two ⅜ inch boiler plates, 6 feet long by 3 feet wide, were rivetted together, and 20 holes to a scale of 1-100th of the actual diameter of the brick cylinders were drilled through them in the relative positions of the cylinders in two piers of the bridge. The plates were then bedded on sand, which was kept constantly wet by water standing at the same level; and the plates were weighted till there was a pressure of 18 lbs. per square inch, equivalent to 42 feet head of water, on the sand, which was then assumed to represent the actual condition of the sand under the pier cylinders when sunk 42 feet. A model to scale of one span of girders was made, resting on 10 cylinders at each end, 1⅝ inch diameter each; the ends of these cylinders were dropped through the holes in the plates, which were drilled slightly larger to let them pass freely through, so that the ends of the cylinders rested on the sand under the pressure of 18 lbs. per square inch. The girders were then loaded with weights, and it was found that with a total load of 15·7 lbs. per square inch on the cylinders they sank 3-8ths inch into the sand; and under a load of 31·4 lbs. per square inch they sank 1-16th inch deeper; but from that point up to the heaviest weight imposed of 157 lbs. per square inch they sank no further, the total sinking not exceeding 7-16ths inch, and that weight remained on for three months without the cylinders sinking any deeper. The load of

157 lbs. per square inch was equal to 10 tons per square foot: but the actual weight of the foundation, pier, and superstructure was 5650 tons on each pier; and the total area of the ten cylinders of 13½ feet diameter in each pier being 1430 square feet, the actual pressure on the foundations was not quite 4 tons per square foot. The experiment therefore proved that the piers were quite safe from sinking deeper in the sand, even under a load of more than double what they had actually to carry.

Mr. F. J. **Bramwell** remarked that the process of sinking the brick cylinders in the manner described in the paper might have the effect of diminishing the sustaining power of the sand, in consequence of the sand not being left dense and close round the cylinders but being disturbed by the act of sinking, the external sand getting forced up into the bottom of the cylinder, and its place being supplied by loose sand running into the vacancy left around the outside.

Mr. **Strong** observed that the more the sand was agitated about the cylinders the faster they would go down; and he had succeeded in sinking three piers of ten cylinders each to the depth of 43 feet in a single season of three or four months. It was only in some cases where the sand was denser that a difficulty had been found in getting the cylinders down.

Mr. E. A. **Cowper** remarked that the sand in the Indian rivers was constantly shifting about, so that what was in one place one season was in another place next season; and therefore it could be of little consequence to the supporting power of the sand whether it were disturbed or not in the sinking of the piers. The sustaining power of sand under compression was shown by the fact that, if a long vertical cylinder with a loose bottom were filled with sand, the pressure on the bottom would be only the weight of the cone of sand resting on the base, all the rest of the sand being supported by the friction against the sides of the cylinder, in a series of cones as it were. Sand was a very good foundation if it was not disturbed at all.

Mr. H. **Woods** stated that about two years ago he was engaged under the direction of Mr. J. T. Woodhouse in sinking a large well at Burton for the supply of water to Messrs. Allsopp's works; the well was 40 feet deep and 40 feet inside diameter, built in brickwork 3 feet thick. The surface of the ground at Burton to a depth of 4 feet was generally ordinary soil, below which was a bed of gravel and sand to a depth of from 30 to 40 feet; and it was through this bed of gravel and sand that the 40 feet well was sunk. Before commencing the sinking, the ground was levelled down to an even surface at the water line of Burton, and an oak curb was laid of 40 feet inside diameter and 21 inches depth, made of a wedge form, the top side being 21 inches broad and the bottom cutting edge 3 inches broad: upon this curb the brick wall was built up to a height of 18 feet in three weeks' time, giving a weight of about 300 tons. The excavation was then commenced, the brickwork sinking as it progressed; the earth was dug out first in the middle and then round the sides close under the curb. The brick cylinder at first canted over slightly to one side, but was speedily got straight again by excavating more material from the opposite side; after which it went down all right without any further accident, and was sunk at the rate of about 1 foot per day, until it had been got down more than 12 feet. The building of the brickwork was then continued and carried on up to a total height of 32 feet, the sinking being continued at the same time; and it was found that the rate of sinking was dependent simply upon the rate of excavating, and the brickwork could be sunk as much as 18 inches per day when the excavation was done more rapidly, showing that the external friction of the ground had not much effect upon the sinking in that instance. In this way the brickwork was got down perfectly safe to the depth of 40 feet, into the position it was to occupy, and the bed of marl below was levelled to form the bottom of the well; it had sunk no further since then, notwithstanding the whole weight of the brickwork amounted to about 600 tons. The well now yielded from 500 to 600 barrels of water per hour, each barrel containing 36 gallons.

Mr. E. **Gilkes** enquired whether the number and size of the brick cylinders in the Jumna bridge were the result of experiment; and what was the cost of construction in that case as compared with the cost of larger cylinders, fewer in number.

Mr. **Strong** replied that some bridges in Bengal had brick cylinders of 18 feet diameter, three in each pier, standing on a solid clay foundation; but the cylinders of the Jumna bridge, 18½ feet diameter, were the largest he had seen himself, and he had sunk also some of 10 and 12 feet diameter. He did not know the relative cost of the different sizes, but the objection to cylinders of large diameter was that they were more liable to crack from not sinking evenly. If the cylinder hung at all in sinking, the brickwork was liable to crack; and some of the cylinders he had been sinking cracked three or four times in going down, but the precaution adopted of building in holding up bolts prevented any injury to the work.

Mr. E. **Gilkes** asked whether boulders were met with frequently in sinking.

Mr. **Strong** said boulders were not very often met with, but when they did occur divers were sent down to excavate the sand around them and break them in pieces, so that they could be got up by the scoop. Sometimes the obstruction was a boulder, and sometimes a piece of driftwood.

Mr. E. **Gilkes** enquired whether the bridge was completed yet and in use.

Mr. **Strong** replied that it was not finished yet: the photograph exhibited showed its state fifteen months ago with the first span of the superstructure completed.

The **Chairman** proposed a vote of thanks to Mr. Strong for his paper, which was passed.

The following paper, communicated through Dr. A. W. Williamson of London, was then read:—

ON A
TYPE COMPOSING AND DISTRIBUTING MACHINE.

BY MR. WILLIAM H. MITCHEL, OF LONDON.

Although the process of printing from moveable types has by the power press been accelerated a hundred fold, the art of composing the types in order to be printed from has not advanced a step since Guttenberg's time. About fifty millions of letters daily are composed and distributed in the United Kingdom; and every one of these is picked from a box by the fingers, and afterwards returned to it in the same manner, without any sort of mechanical aid. Nevertheless during the last twenty years fully twenty attempts have been made by English, French, German, Danish, Italian, and American inventors to effect an economy in this direction. Three inventors have died recently, after devoting seventeen and eighteen years respectively to this subject, and have left the eventual introduction of machinery for composition still a question, and one which printers in general yet decide in the negative. In order to appreciate the efforts of these numerous inventors it is necessary to have a clear idea of the nature of the work to be performed.

The work of the compositor may be divided into five operations:—Composition, Justification, Making up, Correction, and Distribution. *Composition* consists in picking up one by one the various letters or "sorts", out of a wooden tray divided into compartments, called the "case"; and laying them together in line in the order required to form words, with small blocks or blank spaces of a uniform size between the words. As however all the lines of a page must be of the same length, and as all words do not consist of the same number of letters and all letters are not of the same thickness, the lines have to be made to correspond in length, either by dividing a word, or when that is not possible by increasing or diminishing the spaces between the words. This is called *Justification*, and in performing it the compositor begins to measure by eye the length remaining to be filled as the composition approaches the end of the line, and the words to be put into it, and inserts accordingly either larger or smaller spaces between the words. The spaces thus inserted however must not be out of proportion to an unsightly extent with those already in; and hence it generally happens that, notwithstanding all the previous care in composing, some of the work at least has to be gone over again, the spaces already in being taken out and others put in: and the final tightening of the line in the composing stick is done altogether by trial. *Making up* is the dividing of the composed matter into pages of a given number of lines, and does not specially concern the present subject. The same remark applies to *Correction.* Lastly *Distribution* is the process by which the types, after being printed from, are returned each to its proper compartment in the case, ready to be again composed in new combinations. It consists in taking with the finger and thumb of the right hand eight or ten letters from a block of matter held in the left, reading them, and then dropping them successively into their several boxes, which operation is repeated till the whole work is distributed.

These five operations represent the work of the compositor in about the following proportions:—

Composition . . .	55	per cent.
Justification . . .	17	,,
Making up . . .	7	,,
Correction . . .	7	,,
Distribution . . .	14	,,

Of these processes, justification, making up, and correction have never been attempted by machinery. The fifth, distribution, is already very rapidly effected by hand, so that not much scope is left for saving of labour; but inasmuch as all composing machines require the letters to be primarily disposed in lines ready for setting up, it has been found necessary to use machinery to distribute them in that manner: this is however an accessory and not a principal point. There remains only composition, that is the mere setting up of the types, in which to effect an economy. To this therefore, and to the accessory process of distribution in line, inventors have directed their efforts, leaving the other processes to be done in the ordinary way.

It is of course impossible to construct self-acting machinery capable of setting up types; for the matter to be set up varies infinitely, while a machine can produce only a uniform result, the conditions remaining the same. And since a guiding intelligence is needed, the question became, on what kind of apparatus could this intelligence act most rapidly, so as to produce a series of motions simple in themselves, but occurring in a perpetually varying series? The obvious answer was "finger keys," and accordingly all composing machines have been constructed with finger keys. But here a difficulty presents itself. The number of sorts or characters, for each of which a type reservoir and key must be provided, ranges from a minimum of forty to a maximum of more than two hundred. The space required therefore makes it necessary to place some at least of these type reservoirs at a considerable distance from the point at which the letters must meet to form words. Over this distance the types cannot be carried directly by the action of the key, without giving the latter so much to do as to make the fingering stiff and awkward. A secondary means of conveyance from the separate type reservoirs to the common receiver has therefore to be provided: which must be so arranged that the letters from whatever distance will arrive at their destination in the same order in which the keys are touched. As this is the main requirement, the manner of attaining it generally prescribes the character of the details, and may be taken as the distinctive feature of the different inventions for the purpose.

The different constructions of composing machines may be divided into two classes:—those in which each letter is by a rapid motion carried to its destination before the next letter is liberated; and those in which several letters may at the same time be travelling by different routes towards the point of setting up, the means of transit being so arranged with regard to time or distance that the letters shall arrive at their destination in their proper order. To the first class belong Beaumont's and Loughborough's machines, in which the carrying is performed by an arm rotating rapidly in a horizontal plane, the type reservoirs and the receiving line both forming produced radii of the circle described by it, and the action of the key being to bring the type within the sweep of the arm. The second class comprises the machines of Sörensen, Rosenberg, Young, Hattersley, and Alden, together with that forming the subject of the present paper.

In the composing machine of M. Sörensen, a Danish inventor, which attracted much notice at the Paris Exhibition of 1855, the type reservoirs were placed round the edge of an inverted hollow cone, over the inner surface of which the types slid down, and through the apex of the cone to the receiver. This brought all the different sorts within an equal distance of the receiver. On the top was placed a self-acting distributing apparatus to supply the reservoirs with type.

In Rosenberg's machine the type reservoirs were arranged as vertical lines in a row facing and parallel to the keyboard; underneath them was an endless band traversing rapidly from right to left, which carried the letters as they were dropped upon it to the receiver placed at the left of the machine. The drawback to this arrangement consisted in the fact that when a letter near the left had to follow after one coming from the right, time had to be allowed for the first letter to pass to the left before the second key could be depressed; a drawback however which was thought to be counterbalanced by the advantage that, when the letters occurred in a series which extended towards the right along the keyboard, several keys might be depressed simultaneously.

In Young's machine the means of transit from the type reservoirs to the receiver consist of a plate in the form of an equilateral triangle, inclined towards one of its angles, and furrowed by a system of curved grooves converging towards the lowest angle, the type reservoirs being ranged along the opposite or highest side of the triangle. Through these grooves the letters descend by their own weight, and the mode of convergence of the grooves is such that, although the type reservoirs cannot all be at the same distance from the receiver, the length of their route thither is nearly the same; and the time of transit of the letters may therefore be presumed to be the same. A self-acting distributor is also employed, which however works independently of the composing machine.

In Hattersley's machine there are points of resemblance to the preceding, inasmuch as this also causes the letters to descend through a triangular system of converging grooves to the receiver. But a very condensed arrangement of the key action and type reservoirs is adopted in this machine, whereby the distances are made less, and accordingly the triangular guide plate is much smaller, being in a vertical plane, instead of inclined like that in the preceding machine. The delivery by this machine is almost instantaneous, so that each letter almost reaches the receiver before the next letter begins to move. The machine has also the advantage that the line in course of composition is directly under the eye of the compositor. Mechanical distribution is here discarded altogether, the types being distributed in the ordinary way and afterwards arranged by children in the required manner for the composing machine.

The combined composing and distributing machine invented by Mr. Alden of New York is altogether peculiar, and is perhaps the most complex and comprehensive machine yet constructed for the purpose. In the centre is a slowly rotating horizontal wheel, around which, as produced radii, are placed reservoirs for more than two hundred sorts of types. On the circumference of this wheel are fixed sixteen moveable boxes, serving the purpose of hands to take up and deliver the types, eight being for composition and eight for distribution. The matter for distribution is placed at the right side of the machine, and each distributing box as it passes takes away a type, and guided by the position of the nicks cut in it deposits it in its proper reservoir. At the other side of the machine are the finger keys, whose action by an indirect and intricate process sets the mechanism of each composing box as it passes in the position to seize a particular letter, also indicated by its nicks, and carry it to the receiver; so that precisely the same number of letters is distributed and composed, and thus a page of printed matter is distributed line from line and letter from letter, and the letters are recomposed, without once being handled by the compositor.

The Composing Machine now exhibited combines Rosenberg's method of carrying the letters by endless bands, with Young's idea of so arranging their route that all will take an equal time to reach the receiver.

The general arrangement of the composing machine is in a horizontal plane, and in shape it resembles a triangular table, as shown in the plan, Fig. 1, Plate 6. The table is traversed by a series of parallel endless bands A, the return side of the bands passing underneath. These bands are all made to travel with an equal and uniform velocity in the direction of the arrows by passing round the shaft B driven by the steam engine. Obliquely to these and at a somewhat lower level a collecting band C skirts the machine diagonally, deriving its motion indirectly by a round driving cord from the same driving shaft B. Above the bands A stands a row of the type reservoirs or slides D, one band passing under each reservoir. The keyboard E extends along the front of the machine, each key communicating with the type reservoir directly in front of it. The sectional view, Fig. 3, shows the framing, the respective levels of the bands A and C, a section of the bed plate F which supports the type reservoirs D, and the position of the keyboard E. When the types are liberated from their respective reservoirs by the action of the keys, they drop on the parallel bands A, which deliver them on to the diagonal collecting band C, and this in turn carries them to the receiver or setting-up wheel at G.

The parallel bands A, Fig. 1, Plate 6, travel at the rate of about six inches per second, and the diagonal collecting band C at fifteen inches per second. The object of this peculiar arrangement of the bands is that all the letters may take an equal time for their transit from the reservoirs D to the receiver G. Although there are forty reservoirs D and no two are at the same distance from the receiver G, an equal time of travel for each type is obtained by the use of these two velocities only. The route of each letter is made up of two parts, one on the slow band A and the other on the fast band C; and the proportion of these parts varies with the whole distance, so as to give in every case a mean velocity proportionate to that distance, so that the actual total time of passage is the same for each type. Thus in the diagram Fig. 2, Plate 6, if A D be the line of reservoirs; D G, T R, and S F, bands of the parallel series; A G the diagonal quicker moving band, and G the receiver: then S has further to travel than T in order to reach G. But T has the part T R slow and only the part R G fast, whereas S has only the part S F slow and the part F G fast. In order to find the necessary proportion of speed, suppose D and S to start together; then as they are carried on bands of equal velocity they will arrive simultaneously at E and F, when one will still have to travel over E G and the other over F G; in order therefore that they may complete their journey together, it is only necessary that the velocities along E G and F G should be as their lengths. And the same proportion applies to all the cases, the several triangles being all similar. Since therefore all the letters take an equal time to reach the receiver G, any two starting together will of course arrive also together, and any two starting in succession will arrive one after the other in the same succession; and hence any number of letters may be played out in any series from the type reservoirs D, Fig. 1, with the certainty that they will arrive in the same series and with the same intervals between them as at starting. In the hands of a swift operator before the first letter of a sentence has reached its destination twenty or thirty more are already on their way; and although they seem to be in confusion while on the parallel bands A, they resolve themselves into a string as they fall upon the diagonal collecting band C, with intervals of about 1⅛ inch between each of the types.

Following the course of a type in its transit from the type reservoir to the line in which it is composed, Fig. 4, Plate 7, is an elevation, and Fig. 5 a plan, drawn half full size, of a type reservoir D, with the key and key action E, and the endless band A passing underneath. Fig. 6, Plate 8, is a back end view, drawn full size, of three type reservoirs D, and the key action. The type reservoir D is a channel or slide of sheet metal inclined at an angle of about 55 degrees, Fig. 6. It is made with an eye at the back to fit on a pin in the bed piece H cast in type metal. These bed pieces are made to fit into the grooved bed plate F, Fig. 4, and overlap one another so as to hold in a recess the small steel stop plate I, shown black in Fig. 6, which serves as the stop for the types in the reservoir D; and the whole of the parts are put together without the use of screws. When the types are brought up by the stop I, as shown at the first slide R in Fig. 6, the lowest has already passed out of the slide D, but is prevented by friction from falling out. The key E, Figs. 4 and 5, is attached to a rocking shaft J fitted in bearings at each end, and carrying at the end next the type slide an arm K, on which is a small shank parallel with the rocking shaft J. On this shank is placed the striker L, which is formed as a tube fitting freely on the shank, and having flanges projecting from it on each side of the stop I to take the type. The striker is brought up against a stop on the rocking-shaft arm by a light india-rubber spring M. When the key E is depressed, a partial rotary and downward movement is given to the arm K, and the striker L descending takes the type at each end, as shown at the centre slide S in Fig. 6, and forces it downwards until it is clear of the stop I, when the type falls upon the endless band A below. The types in the reservoir, overcoming by their weight the resistance of the india-rubber spring M that holds up the striker L, descend at once upon the stop I, forcing the striker backward, as shown at the third slide T in Fig. 6. The key being now released, the striker rises and recovers its former position by means of the india-rubber spring M. The descent of the key is regulated by a screw underneath, and its ascent by the T headed screw N passing through it, Figs. 4 and 5. Under the key is a very weak conical spring O to raise it when the finger is lifted. One of the advantages of the yielding striker L just described is that this spring O under the key can thus be much weaker, not having to overcome so much resistance in raising the key: this is a point of great importance as regards rapidity of fingering.

The types thus liberated from the type reservoirs are immediately carried on towards the diagonal collecting band C, on which they are delivered by a sort of curved spout, as seen in the plan, Fig. 7, Plate 8, where the types are represented in about the respective positions they would occupy if played out in the succession indicated by the numbers. The types are turned into their new direction by the motion of the bands themselves: it was a point of some difficulty to find a means of transferring them from one band to the other at a high speed without turning them over, and the difficulty was greater with small sizes of type.

The diagonal collecting band C carries the types to the receiver, where they are set up in long lines by a kind of ratchet wheel G, Fig. 8, Plate 9, formed of successive thin steel plates with discs of sheet metal between, as shown full size in Fig. 9, resembling a number of circular saws revolving backwards. On the circumference of this wheel at a point nearly over the centre the types are delivered by means of a small shoot, and slipping into the ratchets are carried round into a vertical position, when they are caught by small steel fingers placed in the interstices between the steel plates of the ratchet wheel, as shown dotted at P in Fig. 8; the following ratchet teeth then acting as cams push the types along as part of the line composed. The shoot and wheel G are tilted slightly, as shown in Fig. 9, causing the types to hug the lower side; and the wheel has one plate of larger diameter on that side, serving as a fence to prevent the types from falling off. The other side of both wheel and shoot is left open, so that if two keys should be touched at the same time or any other accident should cause two letters to arrive together at the setting-up wheel, one is thrown off and no choking takes place, the type thrown off being caught in a tray fixed below.

The lines of type composed in this manner pass out upon a long moveable rod, which when full is emptied on a kind of desk with ledges, where it is justified. This is done in the ordinary way, except that the lines are lifted into the compositor's "stick" with one hand, by means of a grab of sheet metal, slightly curved, having one end hooked and a lug at the other end. The lug being laid hold of by the forefinger and a slight pressure exerted by the thumb upon the end of the line of type, the latter forms itself into an arch in the grab, and may then be lifted without risk of falling to pieces. This is done very rapidly with a little practice. The types once in the composing stick, which is of the usual pattern, the remaining parts of the process, justification, making up, and correction, are performed by the compositor in the ordinary manner.

This new method of composition makes it necessary to adopt a new plan also for storing the type, the old cases being no longer of any use for that purpose. For the composing machines the letters must always and under all circumstances be kept arranged in line. When in store therefore they are placed on thin wooden slats 13 inches long, so formed that a number of them charged with type may be laid together or lifted together. These slats are placed on racks under the composing machine, and in feeding the machine the lines of letter are slipped sideways off the slats into the type reservoirs D of the machine, Figs. 4 and 5, Plate 7.

This composing machine is capable of setting up types at the rate of 6 letters per second or 21,600 per hour; but as the compositor's fingers cannot attain to such rapidity, and allowance has to be made for the operations of justifying and correcting, the work of an average trained compositor will probably not exceed 24,000 or 25,000 letters per day, which is about equal to the work of two men setting up type by hand in the ordinary mode. Each composing machine can employ two men, making the daily production about 50,000 letters with one machine.

When the composed matter has returned from the press, all that remains is to distribute the various types into separate receptacles and replace them on the store slats, so that they may be used again in the composing machine. The first step is to place several lines of a page end to end, so as to form a single long line of letters, in which form they are fed into the self-acting Distributing Machine, the general arrangement of which is shown in the plan, Fig. 10, Plate 10, drawn half full size. The long line of letters is placed in a horizontal feed channel A, in which they are drawn forwards, as successively distributed, by the follower B with a string and weight attached, moving in the direction of the arrow. At the mouth of the feed channel they are cut off singly by the vibrating striker C, and fall into grooves cut in the circumference of the conical distributing wheel D, which revolves horizontally at a slow speed beneath. The distributing wheel D revolves above a stationary base E, also conical, the two forming together a frustum of a cone, as shown in Fig. 17, Plate 11. At the lower end of each of the sixty grooves in the circumference of the distributing wheel is a small pin F, Figs. 17, 18, and 19, on which the types as they fall through the grooves become suspended by means of nicks cut in their sides, but not until their lower ends have passed a short distance out of the grooves, so that the foot of the type projects over the surface of the stationary base E. As the nicks are cut in different positions in the different letters, some types project further from the grooves than others, and so descend further over the surface of the conical base E, as seen in the diagram Fig. 21, Plate 12, which represents an elevation of a portion of the circumference of the distributing wheel D and base E, projected all in one plane for the sake of illustration. On the base E is fixed a series of offsets G, each presenting a horizontal incline to the lower ends of the types, as these are carried round by the distributing wheel; and when the foot of a type comes in contact with one of the offsets it is canted outwards by the incline, until the nick by which the letter hangs becomes clear of the suspending pin F, when the type drops into one of a series of radial receiving lines H in the stationary base E, and is immediately pushed forwards along the line to make room for others, as shown in Fig. 17, Plate 11.

The offsets G, Fig. 21, Plate 12, are arranged in a series of steps ascending in the direction of the distributing wheel's motion, each being fixed a little higher up on the base E and therefore nearer the wheel D than the one behind it. Consequently those letters which project the furthest below the grooves of the distributing wheel are first brushed off, and the rest follow in due succession. As all the letters are thus removed in the course of one revolution of the wheel, the grooves return empty under the feed channel A, Fig. 14, Plate 11, to be again filled; and so the distributing wheel goes on filling, emptying, and refilling itself, till the line of letters to be distributed is exhausted. The receiving lines H, Figs. 17 and 21, placed under the several offsets G, extend outwards radially, as shown in the plan, Fig. 10, and are 13 inches long, each having a small loose sliding block, Fig. 17, to keep the types upright in the line. As each line fills up with its appropriate letter, the contents are slid out by the attendant on to a brass rod, dumped on the store slats, and placed on the racks under the composing machine, ready for use again in composing.

The first difficulty in the distributing machine was to find a means of cutting off the letters one at a time from the feed line A, Fig. 10, Plate 10, as they often adhere strongly together with printing ink, and are moreover of many different thicknesses, some being five times thicker than others. This is effected by the following contrivance. The feed line A when drawn forwards in its channel is brought up at the end of the channel by an inclined stop I, Figs. 11 to 16, Plate 11, formed of a small steel plate, shown black in Figs. 11 to 13, projecting a short distance across the mouth of the channel A, and placed at an angle of 45 degrees to its bed. When a thin letter is foremost, as in Fig. 11, the advance of the line is arrested by the upper edge of the stop plate I, which is sufficiently far in advance of the channel mouth to permit all types under a certain thickness to clear the channel. But in all types above this thickness, a nick is cut in the side of the type, into which the upper edge of the stop plate I passes, as in Figs. 12, 13, and 14; and the advance of the line is then checked, not by the upper edge of the stop plate, but by the lower side of the nick coming in contact with the under sloping face of the plate I. The point at which the type is arrested depends of course upon the distance the nick extends downwards in the type, and this distance is always made proportionate to the thickness of the letter, as illustrated by the types shown full size in Figs. 22 to 25, Plate 12; the nick Q is widest in the thickest type, Fig. 22, and not so wide in the thinner type, Fig. 23, while the thinnest type is devoid of the nick altogether, Figs. 24 and 25. In this manner every letter of whatever thickness is permitted to pass out just clear of the feed channel mouth; and is then cut off by the vibratory motion of the striker C, Figs. 15 and 16, without danger of carrying another letter with it.

The plans, Fig. 10, Plate 10, and Figs. 15 and 16, Plate 11, show the arrangement of the parts for cutting off the letters from the feed line A in the distributor. The striker C is a lever vibrating horizontally on a vertical centre and receiving its vibratory motion from the cam J on the vertical driving shaft of the machine. On the same shaft is a second retarding cam, which presses against the forked break lever K, Fig. 16, serving to retard the advance of the line of letters and prevent a sudden blow of the foremost letter against the stop plate I. The return motion of the striker is effected by a spring bearing against a second spring L, which when pressed upon by the first spring bears against the leading letters of the line A, as in Fig. 16, and holds them steady while the first letter is cut off for distribution, preventing the next letter from being pushed forwards against the end of the striker C. During the first 90 degrees of revolution of the vertical driving shaft J, the retarding cam and break lever K allow the line of letters to advance until the foremost letter is brought up by the stop I; the break lever K then remains pressed against the front letter of the line by a weak spiral spring. In the next 30 degrees of revolution the striker cam J acting against the roller upon the striker C cuts off the foremost letter from the line; and during the next 30 degrees of revolution the striker is held by the cam J in this position, as shown in Fig. 16, Plate 11, so as to give the letter time to drop through the shoot M into the distributing wheel below; in another 30 degrees the striker returns to its original position shown in Fig. 15, the driving shaft J having then accomplished half a revolution. The other half revolution is similar; so that each turn of the driving shaft cuts off two letters, and the driving shaft being geared to the central spur wheel N so as to make thirty revolutions for one of the central wheel, one letter drops into each of the sixty grooves of the distributing wheel D as it passes beneath the striker C. The shoot M, Figs. 13 and 14, Plate 11, conveying the types into the grooves of the distributing wheel, has a guide on one side only, to guide the types into the grooves of the wheel, since the latter moves in the direction of the arrow, Fig. 14; and the grooves have tapered openings with the same view.

The diagram Fig. 21, Plate 12, represents the distributing wheel D charged with types, moving in the direction of the arrow; also the stepped series of offsets G on the base E, and the radial receiving lines H. Fig. 18, Plate 11, is a section of the circumference of the distributing wheel D through one of the grooves, showing the manner in which the types are suspended on the pins F. Fig. 19 is an end view of a groove and type, enlarged to double full size, showing how the type descends through the groove, tilted up with one side resting on the pin F, until a nick occurs in that side, when it drops on the pin and becomes suspended. Fig. 17 exhibits a section and profile of the distributing wheel D and base E, showing how the type, lifted from the pin by the offset G, falls into its receiving line H, and is there pushed forwards by the driver O worked from within the base.

Referring now to the left side of Fig. 21, Plate 12, the type No. 1 is there shown as just dropping into its groove in the circumference of the distributing wheel from the feed channel A of the machine. It is received upon the plate of steel P, attached to a projection of the base E and occupying the small space between the suspending pins and the bottom of the grooves in the distributing wheel D. Carried along by the motion of the wheel, the foot of the type encounters an offset on the steel plate P, presenting a horizontal incline, which pushes its foot outwards far enough to enable it to pass over the plate P and suspending pin, when its fall downward is arrested as at type No. 3 by the edge of the inclined plate R screwed to the surface of the base E; and following the descending incline of the plate R as at Nos. 4 and 6, and with one side resting on the pin F, Fig. 19, Plate 11, the type gradually descends until the nick cut in its side reaches the pin, when it slips on to the pin and thereby becomes suspended, and is so carried forwards, like Nos. 5, 7, 8, 9, and 10. These types it will be observed hang at different heights, and are thus fitted to come in contact with different offsets of the ascending series G. Nos. 11 and 12, having already come in contact with their appropriate offsets, and having been by them lifted off their pins, are represented dropping between the guides into their receiving lines H.

There are only ten offsets in the first stepped series G, Fig. 21, Plate 12, and therefore only ten letters can be distributed by them: but to the right of the diagram is shown a second descending incline R, and the commencement of a second series of stepped offsets G and receiving lines H like the first. There are four of these series succeeding one another round the base E of the distributor, and the manner of using them is as follows. Since there are forty sorts of type to be distributed, and each requires to differ from its neighbour by 1-32nd inch in the position of its distributing nick Y, Figs. 22 to 25, and as only 3-8ths inch of the type's length is available for these nicks, it becomes necessary to use the same nick for several letters. This is done by combining with it a second nick Z, Figs. 23 to 25, placed nearer the foot of the type; so that the type, becoming suspended by this lower nick first, is held above the reach of any of the first series of offsets, and reserved for the second, third, or fourth similar series. Thus the types Nos. 13, 14, and 15, in the diagram Fig. 21, Plate 12, have one nick, the upper one, similarly placed to that in the type No. 12;

but having in addition a nick nearer the foot, their fall has been arrested by this lower nick, and so they have been carried past the place where No. 12 dropped off. When the type No. 15 arrives at the commencement of the class or series to which it belongs, its foot meets with an offset similar to the others, but having a projection below; so that the type, though lifted off its pin, is not permitted to drop; but descending the second incline R similar to the previous one, as at Nos. 16 and 17, it will then become suspended by the upper nick, and will afterwards be finally lifted off the suspending pin and distributed by the corresponding offset of the second series. In like manner the types Nos. 14 and 13, having nicks successively still nearer the foot, will be carried respectively past the second and third divisions and distributed in the third and fourth divisions. The nick Z near the foot, Figs. 23 to 25, which determines the series or class that a letter belongs to, is called the *class* nick; and the upper nick Y which determines the particular receiving line it shall fall into is called the *sort* nick. Since therefore the four series of offsets are all similar, each class nick Z appears in ten different letters, and each sort nick Y in four different letters. If a letter belong to the first series, it has the sort nick Y only, as in Fig. 22, and is at once suspended by this nick and distributed; but if it belong to the second, third, or fourth series, it has the class nick Z also, as in Figs. 23 to 25, sufficiently near its foot to carry it clear of all the offsets till it reaches its own division, when it descends to its sort nick Y and is distributed. All the ten letters of the same class therefore have one nick, the class nick Z, in common; and also sort nicks Y, differing from one another in the same class, but corresponding to the sort nicks of the other classes. In this manner the distributing machine divides the letters just as a naturalist divides his specimens into genera and species; all the members of a class or genus having one feature in common, which serves to distinguish them from the members of the other classes; while each particular type again has a feature peculiar to itself, which serves to distinguish it from the rest in the same class.

The plan, Fig. 20, Plate 11, shows the manner in which the drivers O are worked for pushing the types along in the receiving lines H, Fig. 10. The loose ring S on the centre spindle of the distributing wheel receives an oscillating motion from the connecting rod and crank J on the main vertical driving shaft of the machine, and has the four series of drivers O jointed round its circumference. With every oscillation of the ring S, the drivers O advance and recede, the machine being geared together so that their advance coincides in point of time with the passage of the distributing wheel grooves above the receiving lines H, so that they advance and retire once for each groove in the wheel. On the same vertical driving shaft J is placed the cam giving motion to the striker C at the mouth of the feed channel, Fig. 10, whereby the movement of the striker also coincides with the passage of the distributing grooves below, as already described.

In order to prevent any injury being occasioned by accidental sticking of any of the types in the grooves of the distributing wheel, a stop action is provided for stopping the motion of the machine immediately, which prevents the wheel from damaging the type or receiving any injury itself. For this purpose the distributing wheel D, Fig. 10, Plate 10, is carried round by the motion of the spur wheel N by means of the spiral spring T: on the distributing wheel is fixed a projecting stud, contiguous to a cranked finger U centred on one of the arms of the spur wheel N. In the regular working of the machine this finger runs round loose on the circular plate V below, which forms one end of a stop lever connected with a catch W that stops the main driving pulley X of the machine. But in the event of any accident whereby the distributing wheel D is held back, the finger U is brought up against the stud on the distributing wheel and is thus depressed, thereby depressing the stop lever V and bringing the catch W against one of the stop pins on the driving pulley X. The motion of the machine is thus stopped instantly, until the obstruction has been removed by the attendant, when the catch W is released by a balance weight and the working is resumed as before.

The distributing machine requires only the attention of a boy, and distributes 8000 letters per hour.

The nicks in the types required for the distributing machine are cut in them by means of a plane with three cutter heads, admitting of all the nicks being cut at once. The adjustments for giving the nicks their proper positions are simple and easy, and either new or old types are nicked, usually at a cost of one penny per lb.

The number of characters provided for in the composing and distributing machines now described is limited to about forty. This seems at first a serious defect, inasmuch as the number of characters required even for plain work, counting roman capitals, small capitals, italics, and numerals, amounts to about two hundred. The small number of forty was adopted however from calculation and not from necessity; for the distributing machine is susceptible of considerable extension, and the composing machine of any desirable extension. But in any work otherwise adapted to the machines, the 160 excluded sorts really amount to only from 2 to 5 per cent. of the entire matter; and in consideration of the necessarily complicated character of the mechanism, and the moderate saving to be hoped for at the best, it was thought better to dispense with an extension which would double the cost of the machines while adding but 5 per cent. at most to their efficiency. The extra sorts are therefore placed in a case in the composing machine, and are dropped by hand into a shoot as they occur, passing along on the endless bands with the other types to the setting-up wheel: while in the distributing machine these extra sorts, having no suspending nicks in them, drop off the distributing wheel at the commencement into a separate receptacle, and are then distributed by hand. The composing machine is usually constructed to work three different sizes of type without adjustment; and the distributing machine is capable of adjustment, with a change of the distributing wheel for each size of type.

The economic bearing of these composing and distributing machines, and the results actually obtained in work done where they have already come into use, remain now to be considered. Of the numerous inventions for the same purpose that have been brought forwards at intervals within the last twenty years, some were the subject of much attention; and several were for a time at work, more or less experimentally, but afterwards fell into disuse. And in the case of the machines now exhibited, their progress during the nine years they have been in existence must be regarded as extremely slow. It might have been expected, from the undoubted advantage possessed by finger keys over the hand picking-up process, that a saving would be effected large enough at once to overbear all objection, and lead to the speedy and general introduction of the machines. But this is not the case. The saving has never exceeded 50 per cent., diminishing under less favourable circumstances to little or nothing; while the difficulty of adapting the new method of composition to the present conditions of printing has been very great. That the saving falls short of what might be anticipated is owing to the circumstance that the work of the compositor consists as already stated of several distinct operations, some of them susceptible of mechanical aid, but others either not susceptible or hitherto unattempted. What makes the difficulty greater is that it is not easy to separate one operation from another. For instance it is inconvenient to charge one compositor with the justification or correction of work composed by another: consequently it is impossible to introduce that division of labour indispensable for obtaining the full benefit of machinery. The compositor has thus to pass from an operation in which he is assisted by mechanism to others which are purely manual; and one result of this shifting about is that the machine stands idle about one fourth of each day. A still more serious result is the waste of time inevitable wherever there is frequent changing from one process to another. The mere setting of the types in line, in which alone a saving is effected, amounts as has been stated to about 55 per cent. of the whole work; but even this includes the operation of reading the copy, which cannot be accelerated by machinery: so that the actual fingering of the keys is reduced to about 50 per cent. of the gross work. Supposing therefore that the compositor is enabled by the keys to set up seven letters for one that he could set up by hand, there results only a saving of about 43 per cent. on the whole process.

Another difficulty arises from the extremely irregular and fluctuating supply of work of any given character in printing establishments. Unlike other extensive trades there is in this but little classification. Every printing office undertakes every description of work, from a card to a book. But composing machines are not suited for doing cards, nor for what is called "displayed work", nor in fact for anything but tolerably plain straightforward work; so that frequent variations in the character of the supply are for machines very inconvenient. If these machines could, like the power loom, be kept regularly supplied with suitable work, their success would be assured notwithstanding all drawbacks. A printer possessing sufficient capital, making mechanical composition the basis of his operations, and accepting only such other work as might be a necessary accompaniment of that, would undoubtedly in the first instance encounter difficulty in drawing business out of its accustomed channels, but would in the end be enabled to underbid competitors adhering to the old method. So long however as the present system prevails of doing all descriptions of work in one establishment, hand labour from its versatility certainly possesses an advantage as compared with any machinery.

As to what has been effected hitherto in actual work, it is sufficient to say that a pair of these machines introduced into an establishment in New York about nine years ago are still in use, together with several others afterwards purchased. Five years after their introduction, the proprietor of that establishment made the following comparative statement regarding one work, a Bible, set in english size type, which he had just completed. The 1086 pages of the work were composed on two composing machines, and the distribution was done on two distributing machines. The entire work measured 6½ millions of letters, and was set up in sixty days with 1000 lbs. of type by three apprentices and one journeyman, and the distribution was done by two boys. The cost was as follows :—

	£.
769 pages set up by three apprentices at two thirds price, about .	38
317 " " one journeyman	24
Two boys for distribution, and one for other purposes . . .	13
Total	£75

The same work done by hand composition, but without regard to time, would cost :—

	£.
769 pages set up by three apprentices at two thirds price, about .	86
317 " " one journeyman	53
Total	£139

The cost of the machine work was thus only 54 per cent. of hand setting: but to do the same work by hand composition in the same time of only sixty days would require at least ten journeymen and 2000 lbs. of type.

About two years ago a pair of these machines was placed on trial in the printing office of Messrs. Spottiswoode and Co., London, and the result of a month's performance was 500 hours of small pica reprint produced in 196 working hours. On this occasion the work was done by a compositor from the New York office. Three machines were thereupon adopted by this firm, and several others by printers in London, Bungay, Glasgow, and Oxford. Although it cannot be pretended that in any of these establishments a result so favourable as the above has as yet been attained, still careful calculations show a margin of profit, small indeed at present, but increasing, and reasonably expected to go on increasing as the operators acquire skill and difficulties and opposition of many kinds are smoothed away. Moreover a collateral advantage appears in a diminution in the wear and tear of the type, and a diminution in the quantity of type required to produce a given amount of work.

The whole advantage of the machines may therefore be summed up as follows. First, a saving of about 43 per cent. in the labour of composition, under favourable though not exceptional circumstances. Secondly, a diminution of about 20 per cent. in the wear of type. Thirdly, a diminution of about 30 per cent. in the quantity of type required for a given amount of work.

In conclusion it deserves to be mentioned that, although their progress has been very slow, in no case have these machines when once introduced afterwards fallen into disuse. It seems probable that ground so slowly won will not be lost, and that a portion at least of the great work of composition will hereafter be accomplished with the aid of machinery.

Mr. **Mitchel** exhibited the composing and distributing machines and showed their action, and also the planing tool for nicking the type for the distributing machine.

Mr. J. **Jaffray** was greatly interested in the subject of the paper just read, which he thought had been treated with great fairness, showing clearly the real difficulties that had to be encountered in applying machinery to the composition and distribution of type. There would be a very large field for the use of machinery for the purpose, if it could be adapted for the work of newspaper offices, where rapidity and economy in composing were of so much importance; but the usefulness of the machines in this case would be very much determined by the size of type that could be composed and distributed by them, and he enquired what was the smallest size of type on which they had been employed.

Mr. **Mitchel** replied that the composing machine was not limited as to the size of type that it was capable of setting up; the smallest size of type that it had actually composed at present was nonpareil, and it had composed every size from nonpareil up to great primer.

Mr. J. **Jaffray** observed that in the distributing machine, where the distribution was effected by means of nicks cut in the body of the type, the size of type that could be distributed would be limited by the strength of the type when nicked, which he thought would prevent the distributing machine from being employed for the smaller sizes of type. Even the present single shallow nick that was ordinarily made in the edge of the type rendered the hard metal types now used very liable to break at the part nicked, especially in using the American Hoe printing machines, in which there was some liability of injury to the type in levelling it down upon the press: and in proportion to the smallness of the type would be the weakness caused by the nick. For newspaper work therefore he feared the composing and distributing machines could not be introduced with advantage, first on account of the great number of different sorts of type that occurred in that class of work, such as italics, figures, short lines, and capitals, &c.; and secondly because at the present time a very large quantity of type had to be used of sizes smaller than nonpareil, such as ruby, to which the distributing machine could not be adapted on account of the nicks weakening the body of the type so much.

Mr. **Mitchel** explained that it was not proposed to use the machines for displayed work, such as advertisements, where different sorts of type were used in the same piece of work; but simply for plain straightforward work, such as ordinary book work, not dictionaries or time tables. The machines were also suitable for the editorial and news departments of newspapers; but they had not at present been tried on newspapers at all.

Mr. C. W. **Siemens** observed that both the machines exhibited involved a great many nice mechanical operations and displayed a great deal of ingenuity. The mode of distributing the type by classifying the different letters by means of notches was a highly ingenious arrangement; as also the method of conveying the types in the composing machine by means of the two sets of bands running at proportionately different speeds, whereby the types were set up in the same order in which they were played out by the finger keys. In the case however of two keys being accidentally pressed down at the same instant, two types would arrive together at the composing wheel and one of them would be thrown out, causing a fault in the setting up; but this he suggested might be easily prevented by fixing a tape band extending under all the keys, about ⅛ inch longer than the actual length of the keyboard, so as to have only sufficient amount of slack to allow one key to be depressed at a time. That was the plan adopted in telegraph instruments worked with finger keys, to prevent more than one key being pressed down at once; and he thought some simple contrivance of that sort could be advantageously adopted in the composing machine.

Mr. F. J. **Bramwell** enquired what became of the exceptional types, when a quantity of matter was placed in the distributing machine for distribution, since it appeared the machine was adapted for distributing only 40 different letters, whilst there were in all about 200 different sorts in the ordinary run of matter that would have to be distributed.

Mr. **Mitchel** explained that the remaining 160 different letters would be deposited by the distributing machine in the first receptacle, and would not be carried round by the distributing wheel, as they did not contain the nicks required for distribution by the machine; and they would then be readily distributed by hand, their proportionate number being only very small.

The **Chairman** enquired how many of the machines there were at present in use.

Mr. **Mitchel** replied that taking composing and distributing machines together there were in New York fifteen of the machines which had been at work more than three years; and in three establishments in London there were seven machines, in Oxford one, in Bungay three, and in Glasgow two.

The **Chairman** enquired whether there were as many distributors as composing machines; and he asked what was the cost of the machines.

Mr. **Mitchel** said there were not as many distributors as composing machines, but in some places there were two or three composing machines to only one distributor; and the composing machines might be worked alone without the distributor, the distribution being then done by hand, in which case no nicks would be needed in the type for distribution. The cost of the machines was about £60 for each machine.

The **Chairman** proposed a vote of thanks to Mr. Mitchel, for his paper and the machines exhibited, which was passed.

The Meeting then terminated; and in the evening a number of the Members dined together in celebration of the Sixteenth Anniversary of the Institution.

PROCEEDINGS.

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7 May, 1863.

The General Meeting of the Members was held in the Lecture Theatre of the Midland Institute, Birmingham, on Thursday, 7th May, 1863; Sampson Lloyd, Esq., in the Chair.

The Minutes of the last Meeting were read and confirmed.

The Chairman had much pleasure in announcing that a donation of £50 had been received from the President, marking his sense of the value of the Institution and the interest he felt in its welfare and advancement. He regretted that the President was prevented by illness from being present to take the chair at the Meeting, as he hoped to have done.

The thanks of the Meeting were voted to the President for his handsome donation.

The Chairman announced that the Ballot Lists had been opened by the Committee appointed for the purpose, and the following New Members were duly elected:—

MEMBERS.

Edward Barlow,	Bolton.
William Steel Brown,	Glasgow.
George Crow,	Newcastle-on-Tyne.
John Pitt Kennedy,	London.
John Lancaster,	Wigan.
Samuel Lees, Jun.,	Ashton-under-Lyne.
Matthew Hill Loam,	Nottingham.

William Ryder,	Bolton.
Wallace Cochrane Somerville,	Westbromwich.
John Henry Storey,	Manchester.
John Wakefield,	Dublin.
Joseph Whitley,	Birmingham.
Tom Whittaker,	Nottingham.

The following paper was then read:—

ON THE CONSTRUCTION OF DRAWING ROLLERS FOR SPINNING MACHINERY.

By Mr. WILLIAM WEILD, of Manchester.

The process of laying fibres of cotton, wool, and flax in parallel and continuous juxtaposition, for the purpose of being spun into threads for various manufactures, was performed until little more than a century ago by the workman's fingers, assisted sometimes by a preliminary operation of carding, which formed the short fibres into a soft fleecy roll of about ¾ inch diameter and 10 or 12 inches length according to the size of the card used. The spinning was done by the distaff, a wooden rod, round the top of which a bundle or fleece of the fibre intended to be spun was loosely wrapped. The spinner holds the distaff in the left hand, and the right hand is held about two inches below it, more or less according to the length of the fibre. A continuous lock of fibres is drawn out from the fleece on the distaff by the right hand, and the length between the two hands is twisted into a fine thread by the hanging spindle or bobbin, which is kept constantly revolving by the impulse of the fingers. The thread spun is wound up at intervals on the spindle by stopping the operation of twisting, and winding on to the spindle the length of thread already twisted: and to prevent the spun thread unwinding from the spindle whilst the next length is being twisted, it is hooked through a nick at the end of the spindle.

In 1738 Mr. Wyatt of Lichfield invented a machine for spinning cotton, by which for the first time a continuous thread was spun without the intervention of the fingers; and two factories were built and furnished with his machines, one at Birmingham and the other at Northampton. The cotton was first carded by hand and then passed between two cylinders which delivered the thread on to the bobbin while in the act of twisting. Both these undertakings failed; the machines have long since perished and no model or detailed description of them remains. About five years later Louis Paul of Birmingham along with Mr. Wyatt proposed to spin wool and cotton by a succession of rollers, cylinders or cones, each moving proportionately faster than the preceding, to draw down the thread or sliver to any degree of fineness that might be required. The writer believes he never used such an arrangement, but simply a series of pairs of delivery rollers set in a circular form but without any drawing process. In 1742 a mill was erected in Birmingham where some of Paul's machines were set to work, driven by two asses working in a gin. He experimented for twenty years along with Mr. Wyatt, but nothing of any commercial importance ever resulted from their labours.

About 1765 two persons named Highs and Key experimented upon rollers for drawing the fibres into a continuous thread. There is no doubt but that Arkwright got some very valuable hints from them to enable him to develop the factory system. Whether Arkwright invented the drawing rollers or not, it was left for him to solve the problem how to construct a spinning machine with rollers arranged so that the first pair should draw and supply continuously a uniform sliver of parallel fibres in small portions, while a second pair should take hold of this and gradually draw out the filaments alongside of one another, and a third pair should draw the filaments out still further to the proper extent for being twisted into thread. The twisting he performed with a spindle and a fly, and the machine also wound up the thread on to a bobbin as fast as it was spun. The writer believes that Arkwright was the first to make a practical machine combining all these processes, though the question of the original invention of the drawing rollers is involved in doubt.

For the purpose of "ginning" the cotton, or separating the cotton fibres from the seed, the "roller gins" as they are called are of the most primitive construction, simply and ingeniously made, and are of Indian origin. Fig. 1, Plate 13, shows a section of a roller gin of modern construction, drawn half full size. It is formed of two small rollers about ¾ inch diameter and from 6 to 9 inches long, made to revolve in opposite directions, as shown by the arrows, by means of toothed wheels. The bottom roller turns on fixed bearings, and the upper roller is kept in close contact with it by means of a lever and screw. The cotton seeds are fed forwards between the rollers from the table in front, a space being left between the edge of the table and the bottom roller to allow the seeds to drop down as they become cleaned of the cotton fibres by the revolving action of the rollers. A brush is fixed underneath the bottom roller to brush off any cotton fibres adhering to its surface. It is necessary that gins acting in this way should have rollers of small diameter, say from ⅝ to ¾ inch, because the smaller the rollers, the more obtuse is the angle they present to the seed which is being cleaned, and the seeds are thereby better prevented from being drawn in between the rollers and crushed and mixed up with the cotton fibre. It is evident in referring to Fig. 2 that large rollers present an acuter angle to the seed, and with such rollers the seeds would unavoidably be drawn in and crushed and mixed with the fibre. The great object to be attained in ginning cotton is to get it free from all impurities; and it is found that the smaller the rollers and the slower their motion, the cleaner is the cotton fibre separated from the seeds: for if the rollers are above an inch in diameter and if they revolve very rapidly, they draw in soft, small, and false seeds, crushing them in their passage, and straining and otherwise injuring the cotton fibre.

The most improved gin of the roller class is shown in Fig. 3, Plate 13, drawn half full size, and is constructed with one large roller covered with leather and having small spiral grooves formed round it both right and left. A guard plate A is fixed near the surface of the roller, having a grating along its bottom edge just wide enough for the seeds to pass through to the roller; and between it and the roller a thin steel striker blade B vibrates a short distance up and down with a rapid motion. By this means the seeds are shaken and turned round in contact with the surface of the roller revolving in the direction of the arrow, and the cotton fibres are drawn between the blade B and the roller, while the stripped seeds are rejected and drop down through the space between the blade B and the edge of the feed table, having been thus cleaned of their fibres in a most thorough manner.

In 1793 Mr. Whitney of America invented a machine known by the name of "Whitney's saw gin," which is shown in Fig. 4, Plate 13. It consists of a wooden cylinder with a series of circular saws C, about 8 inches diameter, fixed upon it at regular distances. The edges of the saws project a short distance through a grid, the divisions of which are too narrow to permit the seeds to pass through. Care is taken that the saws revolve in the middle of the grid spaces, for if they rubbed against the bars they would tear the cotton filaments to pieces. A cylinder with brushes D, the tips of which touch the saw teeth, sweeps off the adhering cotton wool from the teeth of the saws by revolving in the opposite direction to the saw roller. The cotton seed as picked from the pods is thrown into the hopper E, and the saws in turning round snatch the filaments from the seed which remains against the grid, and drag them inwards and upwards. The stripped seeds being too large to pass through the grid accumulate at the bottom of the hopper E and are let out at intervals.

The cotton after a further process of cleansing and carding is then ready to be operated upon by the drawing frame, shown in Fig. 5, Plate 14. Five or six cans F placed side by side contain each one sliver of cotton as delivered by the carding engine, and the several slivers are drawn together and combined into one by passing through the drawing rollers G, from which the combined sliver is conducted by the funnel and rollers H into the can I in front of the drawing frame. This process is repeated by combining five or six of the new slivers into another compound sliver by passing them a second time through drawing rollers; and for the manufacture of the finer descriptions of yarns this drawing process is repeated as many as half a dozen times.

In the construction of the drawing rollers G, Fig. 5, Plate 14, the lower roller, which is the only one driven, is of iron and fluted on the surface; the top roller, which has a soft yielding surface, is driven only by friction from the lower roller, upon which it is pressed by a weight J suspended from a bearing in the centre of each roller, as shown half full size in Fig. 6. The pair of rollers are shown in elevation, half full size, in Fig. 7, Plate 15, K being the centre bearing from which the weight is suspended; and the ends of the top roller are plain pivots LL working between vertical guides over the centre of the bottom roller, and free to move vertically, as seen in the transverse section, Fig. 6.

In the first introduction of the new system of drawing cotton by rollers a great difficulty to be overcome consisted in the cotton lapping round the rollers during the drawing instead of being delivered clear of them; and there was also the difficulty of finding a material for the top rollers that should have an elastic surface and yet be durable and perfect in its action, imitating the delicacy of touch of the human fingers in the original distaff spinning, by giving constantly the exact amount of pressure required for drawing the fibre uniformly, so as not to over stretch the thread and thereby vary the thickness of any portion. Top and bottom cleaners M, Fig. 6, Plate 14, consisting of a rubber of flannel fixed on a board lying upon the top roller and held up under the bottom roller by a weight, were applied to prevent the cotton from lapping round the rollers; and previously it had been the practice for the attendant to rub the roller occasionally with chalk, which was the plan adopted by Arkwright and continued long after his time. The application of top and bottom cleaners has to a great extent removed that evil.

The construction of the rollers is a point of great importance, upon which the success or failure of the drawing process really depends. The ordinary top rollers are those made with an iron centre, painted with white lead and covered with thick felted flannel made for the purpose, over which is placed a cover of specially prepared leather. The importance of good top rollers in spinning cannot be over estimated; but as hitherto constructed in the manner just described they have several radical defects, which make it impossible to spin or draw cotton of uniform thickness or "counts." The top rollers are made in pairs with two roller surfaces or "bosses" as they are termed upon one spindle, and as ordinarily constructed these two bosses are solid upon the spindle. Practically it is impossible to get the two bosses of exactly the same diameter when clothed, owing to the varying thickness of the leather. Then if one of them be 1-16th inch larger in diameter than the other when covered, the result will be a contention for speed between the two bosses; for by the time one has made 20 revolutions the other wants to have gone 21. This causes slipping and abrasion of the surface of the leather, which causes the cotton to lap round the roller, and wastes the fibre of the cotton drawn, besides destroying the leather; and the roller also gives out irregular lengths of yarn or sliver. Again the ordinary roller requires oiling many times a day, owing to the bearings being all external and soon getting dry from the flakes or particles of cotton collecting about them and soon absorbing the oil; and in proportion as the bearings get dry the top roller drags and loses its speed, and the yarn or sliver becomes thicker. When oil is applied the roller goes freely for a time, giving out a greater length of sliver. By this frequent necessity for oiling not only is a great waste of oil occasioned, but the oil saturates and helps to destroy the cloth and leather covering of the roller, producing extra sticking and waste of the cotton.

Figs. 7 and 8, Plate 15, show half full size the most improved construction of these top rollers, the invention of Mr. Evan Leigh of Manchester. N N are the two bosses of the top roller, which are both loose upon the spindle, and G G is the corresponding bottom roller. The bosses of the top roller in this case revolve entirely upon the spindle, and the spindle remains stationary, instead of revolving within the hook that carries the weight and between the end guides as in the old plan. A section of one of the bosses of the top roller is shown in Fig. 7, showing the conical form of the end journals L L of the spindle, which in conjunction with the coned holes at the ends of the rollers gives a capillary action always drawing the oil from the end bearings L inwards into the parallel portion of the spindle inside the roller. The inner ends O of the spindle are coned down in a similar manner, and the oil is thus prevented from escaping from either end of the rollers. The body of the rollers N N is of cast iron, bored out with great accuracy and care, and is covered first with flannel and then with leather. The spindles are also of cast iron, and the weight for giving pressure to the top rollers is suspended from the centre K between the two bosses. Each boss N can now run at its own speed independent of the other, and thereby each delivers out correctly its proper length of sliver. The leather keeps smooth, and saves waste of cotton; and the bearings being internal and completely covered, the roller does not require oiling for weeks. These top rollers save the couplings of the lower rollers by taking less power to drive them, and avoiding the retarding action like that of a break, which was produced by the upper roller slipping over the fluted surface of the lower roller to the extent of the variation in diameter of the bosses on the upper roller. The spindle being made of cast iron as well as the roller, the tendency to wear is reduced to a minimum; for when two surfaces of cast iron have worked together a short time, the oil becomes absorbed in the pores of the metal, which attains a high polish, runs light, and becomes as hard and indestructible as glass. These top rollers run from one to six months without lubrication, according to the quality of oil used.

Another difficulty that spinners have had to contend with is the fluting or cutting up of the leather surface of the top roller by the action of the flutes in the bottom roller. When this occurs the fibres of the cotton get crimped and cut or broken in the act of being drawn, by passing between the two corrugated surfaces, and a greater length of thread is delivered than when the top roller is kept perfectly smooth: but the spinning of good yarns depends upon the regularity of all the threads as to quantity of fibre and length delivered. The bottom rollers were formerly fluted by longitudinal grooves cut with a tool at equal pitch all round the roller, and the impression left upon the top roller was consequently of uniform pitch, and continued deepening by the pressure of the corrugations always coming upon the same parts.

About twenty-five years ago a simple method of fluting the bottom rollers irregularly was introduced with a view to remove or correct the fluting of the leather rollers; this plan is illustrated in Figs. 9 and 10, Plate 15. The ordinary roller fluting machine may be said to be an ordinary planing machine with the addition of a ratchet motion to turn the roller from one flute to the next after each cut. The method of fluting the rollers with irregular flutes was as follows. A disc P was keyed upon the end of the roller G, on which a ratchet plate R was placed eccentric to the centre S of the roller and disc P. The click T of the ratchet moved the ratchet one tooth round after every cut of the tool U, and thus the flutes nearest to the centre of the eccentric ratchet R were closer together than those further removed from that centre, and therefore the more eccentric the ratchet the greater was the disproportion of the distances between the flutes. This is illustrated by the two segments shown by the dotted lines in Fig. 9, which at their outer extremities are the same width, namely the breadth of one tooth of the ratchet R; but where they intersect the circumference of the roller at V and X, the distance of V from the centre of the ratchet being double that of X, the breadth of the segment at that point and consequently the pitch of groove cut is also doubled. This arrangement to a certain extent obviated the tooth and tooth action which took place in the ordinary regular fluted rollers, the irregular pitch of the flutes in the new method causing their impressions upon the top roller to vary in position at each revolution; but it was not effective in saving the top roller unless there were considerable difference in the breadths of the flutes, which gave rise to another evil, namely irregular drawing of the cotton fibre: in fact in this plan a bad drawing roller was used to save the top roller.

The latest improvement in the fluting of spinning rollers was introduced by the writer about three years ago and is now being extensively adopted. Up to that time all rollers for drawing cotton and other fibres had been made with straight flutes parallel to the axis of the roller. The improvement now made in the fluting consists in forming the flutes spirally on the rollers, at an inclination of about 1 in 12 to the axis of the roller, as shown in Fig. 7, Plate 15, the grooving being done in the ordinary fluting machine with the simple addition of a twisting motion for the roller while in the act of cutting, similar to a rifling action in gun manufacture. By this means the upper roller rests upon several flutes at once, their number depending upon the length of each roller and the length of twist of the spiral flutes, instead of resting upon one straight flute as in the ordinary roller. In the ordinary roller, the flutes being parallel to the axis, the upper roller must make a slight ascent and descent in passing over the top and groove of each flute; while with the spiral flutes the top roller is uniformly supported and will not have the least rise and fall. A further improvement is made by inclining the flutes of one roller in the reverse direction to those of the next, as shown in Fig. 7; so that by turning end for end the top rollers, which are in short lengths, any tendency of the leather to flute may be corrected, since the flutes formed by one roller would be wholly or partly effaced by the reverse spiral of the flutes in the other roller.

All the forms of rollers that are grooved in a planing machine have a defect from the edges of the grooves being left keen with a slight burr upon them, which would cause the cotton fibre to adhere to the surface of the rollers. To prevent this a careful and tedious hand process has to be gone through with each roller, after cutting the flutes, in order thoroughly to smooth down the grooves by longitudinal rubbing with stone and emery; and the rollers are then polished by revolving in the same direction in which they are intended to run in working.

A very rapid method of manufacturing these spiral fluted rollers by means of a milling tool has been introduced by the writer, in which the whole process is completed at one operation, leaving the roller finished ready for putting to work without any intermediate preparation being required. The machine for this purpose is represented in the front elevation, Fig. 13, Plate 16, and the transverse sections, Figs. 14 and 15, Plate 17; and Figs. 16 and 17, Plate 18, are enlarged views showing the details of the milling process, drawn half full size. The roller A to be fluted is laid on friction rollers B B, Figs. 16 and 17, supported by adjustable stands upon a saddle C C fixed on the main bed of the machine, Figs. 13 and 14. The milling tools D D, shown full size in Figs. 11 and 12, Plate 15, are steel discs about 2 inches diameter, and $\frac{3}{8}$ inch wide on the edge which has upon it a counterpart of the flutes to be impressed upon the roller. Each milling tool is carried by a cranked lever E working on a centre at E, Figs. 14 and 15, Plate 17, and acted on by the weight F, which exerts a downward pressure upon the milling tool of about 1200 lbs., regulated by shifting the weight F to the extent required. The milling tools are thrown out of action by the eccentric shaft G being turned half round, which depresses the tail end of each of the four levers E, lifting the weights F, and raising the mills D from off the roller, as shown in Fig. 15, Plate 17. The mills are first placed about ⅛ inch upon the ends of each roller to be cut, as shown dotted in Fig. 16, Plate 18; four roller bosses all on one solid spindle are milled at one and the same time. The roller to be milled is turned by the driving pulley H, Fig. 13, Plate 16, through a universal joint I, in order to prevent any strain upon the roller during the process. The milling tools with their levers and weights are all carried by a sliding carriage J J, and traversed along the bed of the machine by a screw K with a self-acting feed, as in an ordinary slide lathe. When the carriage J has traversed the length of one of the bosses of the roller, the machine is stopped by the handle and strap rod L; and the mills are lifted up from off the roller by turning the eccentric G. The carriage J is then moved forwards by the handle M, on which is a pinion working into a wheel on the same shaft as the crown wheel N gearing into the traversing screw K. The four mills are thus brought into a position to start milling the four remaining bosses of the roller. The weights F are then let down, causing the mills to bear on the roller; and the crown wheel N being locked by the handle O, the carriage J will then traverse the mills over the bosses. The mills work at the rate of 60 revolutions for 1 inch of traverse, the roller revolving at the rate of about 120 revolutions per minute; and the mills being about double the diameter of the roller, the fluting advances about 1-120th inch in each revolution of the roller.

Rollers manufactured in this way by milling have a much harder surface and will consequently wear much longer than those fluted by the ordinary cutting system, the surface of the metal being condensed by the pressure in the milling process. Another advantage is that the grain of the iron is laid in the best direction for ensuring smoothness of action in the working of the roller, since the roller is driven in the milling process in the same direction in which it is intended to run in the drawing frame; and the mill leaves it sufficiently polished to be immediately used for drawing.

The drawing rollers are from 1¼ to ⅝ inch diameter, and 16 to 22 inches length, with from two to eight bosses of proportionate length upon each; and the several rollers are coupled together by square spigot and socket joints formed on the ends of the rollers, as shown in Fig. 18, Plate 19, extending to a total length of 30 to 120 feet, all driven from one end. The manufacture of spinning rollers has of late years been much improved by the introduction of special self-acting tools for each operation. First, the bar of iron is cut up into lengths, which are then heated and rolled between three rollers to make them true and straight. Secondly, rough squares are forged at one end of each bar with a Ryder's hammer, to form the spigot. Thirdly, each bar is cut to the exact length required, and a hole is bored up longitudinally about 3 inches at the other end, as shown full size in Figs. 19 and 20, Plate 19, six rollers being bored at a time in a multiboring machine. Fourthly, the round holes thus bored are squared out for the coupling by means of three punches, as shown in Figs. 21, 22, and 24, each punch larger and shorter than the preceding, so as to allow room for the shavings to lie at the bottom of the hole, as seen in the longitudinal section, Fig. 23. The last punch, Fig. 24, does not entirely square the hole, leaving a space to allow the air to escape from behind the punch in order to prevent risk of bursting the socket; and thus a portion of the original circle is retained on each side of the square socket for centering the roller truly in the subsequent turning process. For squaring up the spigot end of each roller, Figs. 25 and 26, four or six of the rollers are put upon a machine with as many vertical tools, and two opposite sides of the square are cut at once by a pair of tools, the roller being carried by the centres at the ends so as to ensure the square being truly central with the roller. The roller is then turned one quarter round and the remaining two sides are cut in the same manner as the two former ones. The rollers are then fitted into one another, as shown in Fig. 18, and marked as they are intended to work in the spinning machine; and they are turned in pairs to ensure their running true. They are then ready for the fluting machine already described.

Figs. 27 and 28, Plate 20, show a set of drawing rollers drawn full size. P and R are the carrying rollers, in which the top rollers are sometimes made of iron, smooth or corrugated, and sometimes covered with leather, P being the back or feeding rollers; and S are the main drawing rollers, the upper one covered with leather, which run about seven times the surface speed of the first rollers P. In Fig. 27 the three pairs of rollers are placed close together for short fibred cotton, and Fig. 28 shows them further apart for long fibred cotton. As the different qualities of cotton vary in length of fibre from $\frac{5}{8}$ to $1\frac{1}{8}$ inch, the proper adjustment of the rollers is absolutely necessary for perfectly attenuating the mass of fibres passing through the drawing rollers. The distance from the centre of one pair of rollers to the centre of the next pair, or the "nip" of the rollers as it is called, should in no case be less than the greatest length of the cotton fibre, or else the fibres would get broken or pulled asunder by being still held by the back rollers when caught at the front end by the drawing rollers running at the higher speed. If on the other hand the successive pairs of rollers were too wide apart, the shorter fibres would not be taken hold of in a perfect manner, not being caught hold of by the quick rollers soon enough after being let go by the former rollers, thereby making a false or irregular thread.

A set of drawing rollers and a bundle of fibre is shown in Fig. 29, Plate 20, the rollers being drawn full size, with the actual distance between the successive pairs longitudinally, but with the vertical space between the two rollers in each pair exaggerated for the purpose of illustrating the nature of the drawing action: PP are the back or feeding rollers, and SS the main drawing rollers. It is of the greatest importance for the production of good and regular yarn that the sliver of cotton fibre should be regular in thickness, and also fed in with a regular continuous motion. In order to illustrate the action more clearly, the fibres are represented in the diagram, Fig. 29, alternately white, shaded, and black; and the length of the fibre corresponds with the distance from centre to centre of the successive pairs of rollers. The number of fibres in the sliver entering the feed rollers PP is represented as 10 in the diagram; and the ratio of speed of the second pair of rollers RR to that of the first pair being taken for the purpose of the diagram as 10 to 7, the fibres get drawn out past one another until they represent 7 fibres in thickness under the second pair of rollers R. The third pair or main drawing rollers SS run quicker than the second pair in the assumed proportion of 7 to 3, and consequently the fibres passing through the third pair S are represented by 3 in thickness of sliver. Thus the sliver or bundle of fibres in passing through the three sets of rollers would in this case be diminished in thickness in the proportion of 10 to 3, and increased in length in the same proportion: so that the greater the difference of speed between each pair of rollers, the finer is the yarn produced. In practice the third or main drawing rollers S run about seven times the surface speed of the first rollers P, as previously stated; so that the sliver of fibres is reduced seven times in thickness of fibre, and increased seven times in length. It is said that the first inventors of the drawing rollers got their ideas from the action of rollers drawing or rolling iron; but it is evident that the drawing out of the fibres of iron for the purpose of elongating a dense mass of material is performed on a very different principle from the drawing action produced by a series of rollers running at different speeds on a large number of short loose fibres of fragile texture.

The spinning of short fibred cotton is practically limited by the smallest diameter that the drawing rollers can be made so as still to allow of constructing coupling sockets in the several lengths of the rollers, sufficiently strong to transmit the power required for a long length of rollers. The great bulk of the cotton machinery in this country is made for drawing cotton having a length of fibre or staple of 1 to 1½ inch, comprising the better qualities of cotton, namely

New Orleans and African cotton .	1 to 1¼	inch length of fibre
Brazil	1 to 1½	„
Egyptian	1 to 1⅝	„
Sea Island	1½ to 2¼	„

as shown full size in the diagram, Fig. 30, Plate 20. But the cotton from the new sources of supply now being introduced has a much shorter length of fibre, namely

East Indian and Nankin cotton . . ⅝ to 1 inch length of fibre

as shown in Fig. 30; and for the purpose of drawing this cotton it is requisite that the diameter of the rollers should not exceed ⅝ inch, in order to bring them close enough together to deal with ⅝ inch fibre. The roller bearings are made to slide transversely, as shown in Fig. 6, Plate 14, so as to be accurately adjusted to the particular length of fibre in each sample of cotton to be drawn; and the rollers have to be small enough for the shortest fibre intended to be drawn.

Wrought iron is not satisfactorily applicable to rollers of so small a size as ¾ inch diameter when carried to a great length; for in addition to the weakness of the couplings the total amount of torsion in a long length of rollers causes the time of action to be sensibly different at the two extremities of the machine, so that the delivery is too slow in starting at the far end, thus giving an undue stretch upon the yarn and occasioning breakage at those parts. To obviate this difficulty a trial has recently been made by the author's suggestion of Bessemer steel instead of wrought iron as the material for the rollers, and this has been successfully adopted in some mills. Steel rollers have been formerly tried in a few cases, but the great expense prevented their adoption; whereas the moderate cost of the Bessemer steel admits of its use, whilst its fine homogeneous quality renders it specially suited for the purpose. A sample of these rollers is exhibited, together with working models of a box or set of drawing rollers, throstle rollers, and mule rollers.

Mr. **Weild** exhibited a drawing frame in action containing a set of the spiral fluted rollers and the improved top rollers; with specimens of the fluted rollers in different stages of the manufacture, and of the Bessemer steel rollers, and the milling tools employed for milling the rollers; also a specimen of the roller gin for cleaning the cotton from the seed.

The **Chairman** thought the plan now described of milling the drawing rollers by the pressure of a milling tool, instead of cutting each groove separately in a planing machine, was highly ingenious;

and in combination with the spiral direction of the grooves must be most beneficial in preserving the leather surface of the top rollers from injury by indentation. The employment of Bessemer steel for the rollers appeared an improvement of special value at the present time, if it would enable the new short-staple Indian cotton to be drawn and manufactured with the same facility as the old American and other cotton of greater length of staple, by the adoption of drawing rollers of smaller diameter than those hitherto used. He enquired to what extent the small diameter rollers of Bessemer steel were now employed, and how long the spiral fluted rollers had been introduced.

Mr. Weild replied that a mill at Preston was the only one at present furnished with the small rollers of Bessemer steel; but the spiral fluted rollers grooved by the milling process had been introduced about 3½ years ago, and were now being employed in more than three hundred mills in Lancashire and Yorkshire. During the last twelve months great numbers of the old rollers had been replaced by the spiral milled rollers, the stoppage of the works for want of cotton affording a good opportunity for making the change.

The Chairman enquired whether the smaller rollers could be applied with equal facility to the long fibred cotton, if the latter were again supplied in the same abundance as formerly.

Mr. Weild thought there would be no difficulty in applying the small rollers to the long fibred cotton; it would only be necessary to move the successive pairs of rollers further apart, to correspond with the greater length of fibre, which was easily done, as the roller bearings were carried in slots so as to admit of any adjustment horizontally: and the difference in the degree of contact of the top leather roller upon a bottom roller of 1 inch diameter or upon a bottom roller of only ⅝ or ¾ inch diameter was so slight that it was scarcely capable of producing any perceptible difference in the drawing of the cotton. The prejudice against using small diameter rollers was owing to the expense attending their introduction into the present drawing frames; because it was not merely that the large rollers were removed and replaced by the small ones, but for this purpose the whole of the roller stands had to be removed and replaced by others having the roller bearings closer together, in order to suit the smaller diameter of the rollers, which involved a very heavy expense. The change was now being made in another factory at Preston. He showed a specimen of a roller frame fitted with a set of the small rollers, the front and back pairs of rollers being ¾ inch diameter, and the middle pair ⅝ inch diameter.

The **Chairman** asked what was the speed at which the rollers could be grooved by the milling process, as compared with the old method of planing the grooves; and also how the mills were made.

Mr. **Weild** replied that by the milling process a roller could now be completely grooved ready for use in less time than it took to fix the roller for cutting in the old planing machine and get the machine ready for work. It took about 1¼ minutes to mill a roller of eight bosses, milling four at a time. For making the mills a master roller was first made of exactly the diameter of one of the bosses of the drawing rollers, which was fluted spirally in a planing machine with grooves of the exact depth and pitch required, and afterwards casehardened. The soft iron mills were then put in the milling machine, and were themselves milled by the hard master roller, and afterwards casehardened. The iron used for the mills was made from scrap consisting of "card teeth," the fine wire teeth of the carding machines: the mills were thus not steel, but iron casehardened, which was found more suitable, since the best steel was found to crack and fly under the heavy pressure of milling. What was wanted was a hard and tough quality of metal, having a surface hard enough for indenting the rollers in milling, but not so brittle as to crack under the pressure; and these qualities were admirably combined in the casehardened iron made from the card teeth. It was now a regular trade in Manchester to make that iron from the card teeth to be used for the engraving rollers employed in calico printing; and for that purpose no kind of steel would do that had the least flaw in it. He showed specimens of the mills that had been in constant work for six months and were not worn out yet, exhibiting scarcely any signs of wear at present. He showed also a specimen of a roller milled to a much greater depth with two opposite spirals of rapid pitch, producing a deeply "pitted" or grated surface; such rollers were required for drawing off the cloth from looms, and were previously made by punching a piece of sheet iron in the manner of a grater, and wrapping it round a wooden roller with the rough side outwards.

The **Chairman** remarked that the homogeneous character of the Bessemer steel would be a great advantage in the manufacture of the drawing rollers, and its superiority to ordinary steel in that respect was clearly seen in the two specimens of rollers now exhibited, one of the Bessemer steel and the other of ordinary steel, the latter having its surface full of minute lines while the former appeared perfectly homogeneous and free from even the faintest appearance of marks. In respect of strength, he had tested a great deal of the Bessemer steel, and found it had nearly double the tensile strength of the best wrought iron.

Mr. **Weild** observed that the steel he had used for the small drawing rollers was not the best Bessemer steel, but was obtained at a cost of about £25 per ton. It was completely homogeneous and free from cracks, and answered the purpose very well for the drawing rollers. It was not necessary to make the rollers of the very best Bessemer tool steel, because they had not to be tempered after the milling.

Mr. J. **Fernie** thought the new mode of fluting the rollers was a beautiful and ingenious application of the milling process and much superior to any plans of milling previously in use. He enquired whether any attempt had been made to apply the same method of milling for making rimers for rimering out circular holes.

Mr. D. **Joy** observed that the milling process had the effect of rounding the edges of the grooves instead of leaving them square and sharp as in the former planed grooves; but a rimering tool required square cutting edges, not rounded off, which could not he thought be obtained by milling.

Mr. **Weild** said he had not tried the milling process for any other purpose than that described; and there was a sort of tooth and tooth action between the milling tool and the roller, whereby the edges of the grooves were necessarily rounded off, which was an advantage in the make of drawing rollers. The success of the operation depended on taking in very small portions of the surface successively to be acted upon by the mill: if it were attempted to mill one of the rollers by placing the whole of the ⅜ inch edge of the mill upon the roller at once, it would be impossible to indent the surface; but by beginning with a very small length of roller under the mill, and advancing the mill lengthwise on the roller only 1-120th inch in each revolution of the roller, the fluting was accomplished without any excessively severe pressure; and the remaining portion of the edge of the mill acted as a polisher following the milling, so that the flutes were milled and polished all at one operation. The result of using the milled rollers was that, in consequence of the roundness of the edges of the flutes and their spiral direction, the leather of the top rollers continued in good condition with a smooth surface for a much longer time; and this was a very important point, since a nice even yarn was obtained in spinning as long as the leather remained uninjured, but not after its surface became roughened by wear.

Mr. J. **Fernie** enquired how the rollers were got true in line and diameter, so as to run perfectly steady for such a long length as 130 feet, made up of so many short lengths jointed together.

Mr. **Weild** explained that all the coupling sockets and spigots were cut by machinery, the rollers being accurately centred on the same centre holes in each operation, whereby perfect truth of work was obtained. The bar to form the roller, after being forged roughly at one end to the required square for the spigot, had a centre hole drilled at each end for centering it in the boring machine, where the socket hole was drilled and afterwards squared out to the exact size by three punches, working longitudinally and following one another in the hole: the roller was then centred by the same centres in an upright slotting machine for squaring the spigot end, and the two opposite sides of the square were cut simultaneously, after which the roller was turned one quarter round, and the two other sides cut in the same way. The rollers were then fitted together and marked, and afterwards turned in pairs in the lathe: Nos. 1 and 2 were first turned together; then No. 1 was removed, and No. 3 was turned with No. 2; then No. 2 was removed, and No. 4 turned with No. 3; and so on. By this means the whole length of a long line of rollers was made to run perfectly true.

Mr. J. **Fernie** asked how the covering of the top rollers with leather was performed.

Mr. **Weild** explained that the cast iron boss of the roller was first painted and covered with a layer of felted flannel; and then the leather was wrapped round outside by machinery, and a knife in the machine set at an inclination cut it off with a bevilled edge so as to lap accurately without increasing the thickness of leather at the joint: at the same time a glue brush was passed along the edge, sticking it down securely with strong glue. The top rollers were required to be both durable and elastic, and the leather formed a durable external covering, while the layer of flannel underneath gave the elasticity required to prevent the cotton fibres being injured in drawing.

Mr. D. K. **Clark** enquired what description of leather was used for covering the rollers; he understood that pigskin had been employed lately for the purpose.

Mr. **Weild** believed the leather generally used for covering the rollers was common sheepskin, prepared slightly for that particular purpose.

The **Chairman** proposed a vote of thanks to Mr. Weild for his paper and the numerous specimens he had exhibited, which was passed.

The following paper was then read:—

ON THE LOCOMOTIVE ENGINES IN THE INTERNATIONAL EXHIBITION OF 1862.

BY MR. D. K. CLARK, OF LONDON.

The collection of Locomotive Engines shown in the International Exhibition of 1862 may be adopted as a fair average exponent of the best and most recent practice both English and Foreign, particularly the former. The English engines were mainly examples of the standard classes in general use on the principal English railways. The Foreign locomotives showed greater variety, boldness, and originality of design, and were mainly constructed for lines with very heavy gradients and sharp curves, which are generally associated together in mountainous districts, causing special mechanical difficulties not applying to the general circumstances of the English railways.

Twenty engines altogether were exhibited, of which eleven were contributed from the United Kingdom, three from France, one from Belgium, two from Austria, one from Prussia, one from Saxony, and one from Italy. Of the above twenty engines, fourteen had outside cylinders, and six had inside cylinders; and of the eleven English engines seven had outside cylinders, and four had inside cylinders. Most of the engines were specially constructed for burning coal: a feature which has been introduced entirely since the former Exhibition of 1851, on account of the smaller cost of coal for fuel compared with coke. The principal particulars of the locomotive engines exhibited, both English and Foreign, are given in the Table appended.

English Locomotives.—Amongst the English locomotives may be noticed first, as specimens of the largest class of Express engines, two exhibited and manufactured by the London and North Western Railway, one with inside and the other with outside cylinders, but both with 7 ft. 6 ins. driving wheels, and designed with special regard to the running of the express trains on that line.

Of the Inside Cylinder class only three engines were made, as it was found to be heavy on the road and in consumption of fuel. It is an engine of maximum dimensions, and indeed must be considered beyond the capacity of the narrow gauge for proper working. With cylinders of 18 inches diameter and a stroke of 24 inches, 7 ft. 6 ins. driving wheels, and 26 square feet of grate, it weighs 34¾ tons in working order, of which there are 14¼ tons on the single pair of driving wheels. With the tender, weighing 25 tons with fuel and water, the total weight to be moved amounts to about 60 tons, exclusive of the train. The boiler has been designed for burning coal, with a combustion chamber and a double compartment of the firebox for alternate firing, to which have been added firebrick arches inside and deflecting plates in the doorways. The grate is 7 feet long in two parallel strips, and the enormous amount of 242 square feet of heating surface has thus been attained in the firebox and the combustion chamber; making the "direct" heating surface greater than has before been attained on the narrow gauge. But the advantage of "direct" surface, or that which is exposed to the radiant heat of the fire, depends upon its being within a reasonable distance of the grate; whereas in this firebox the crown is 6 feet 3 inches above the grate, and the upper portions of the surface are therefore nearly ineffective for evaporation. This great extension of firebox and combustion chamber has led to the curtailment of the tubes to 9 feet 4 inches length, and it has been attempted to compensate for this by packing 214 tubes together at ·50 inch distance apart, making 980 square feet of heating surface in the tubes. The opinion has been extensively held that heating surface is mechanically the equivalent of evaporating power, but this in the writer's opinion has not been confirmed by practice; for besides surface, circulation is wanted; the circulation of the water to the tubes, and of the steam from amongst them: and in this particular engine the evaporative power of a smaller number of tubes placed at ·75 inch apart would have been greater than that of the tubes as they are. The driving and leading springs are connected by a compensating beam, which seems likely to give an unsafe freedom of action to the engine at high speeds.

The Outside Cylinder engine, exhibited by the London and North Western Railway, is one of a numerous class running the express trains on that line, and contrasts in several respects with the inside cylinder engine. It weighs only 27 tons in working order, and the tender 17½ tons, making a total of 44½ tons, as against 60 tons for the other engine; and the weight on the driving wheels is only 11½ tons instead of 14¾ tons. The weights on the several wheels are,

	Inside Cylinder engine.	Outside Cylinder engine.
Leading wheels	11·90 tons	9·40 tons.
Driving wheels	14·80 „	11·50 „
Trailing wheels	8·50 „	6·10 „
Total weight .	34·70 „	27·00 „

The firebox is of the ordinary form, with little more than half the grate surface of the other engine; and it is fitted for coal burning with a firebrick arch and two air openings in front, closed by a regulating flap, as shown in Figs. 1 and 2, Plate 21, which show a longitudinal and transverse section of the firebox. The heating surface of the firebox is 85 square feet, being little more than one third that of the inside cylinder engine; and there are fewer tubes, but then they are ·62 inch apart. The other engine gains the advantage in the greater size of blast orifice, which is 5¼ inches diameter for the inside cylinder engine, and 4½ inches for the outside cylinder engine; owing to the larger area of grate in the former engine, which does not require the same sharpness of blast to draw the air through.

Regarding the engines as carriages, the height of the centre of the boiler in the inside cylinder engine, 7 feet 5½ inches above the level of the rails, is considerable, and tells upon the rails when the engine sways. In the outside cylinder engine, though the driving wheels are as large, the centre of the boiler is 11 inches lower; and this in connexion with a compact wheel base and a balanced driving wheel, produces a safe steady and easy-running engine. In both the engines feed pumps are displaced by two Giffard's injectors.

The outside cylinder engine is fitted with a duplex direct-action safety valve, in which a pair of valves are pressed down by a crossbar with a spiral spring attached to the middle of the bar, between the two valves, as described at a former meeting (see Proceedings

Inst. M.E., 1856, page 37); a decidedly superior arrangement to the ordinary weighted lever, since this valve cannot be tampered with, and is much more prompt in discharging an excess of steam, as it opens wider for a given excess of pressure. The smokebox is furnished with a descending hopper at the bottom, having a small opening not closed, through which ashes and ignited cinders are allowed to escape constantly; thus overheating of the smokebox is prevented. The reversing gear is worked by a screw and handwheel, instead of the usual long lever and notched sector; this reversing gear, which is applied to nearly 200 engines, is more easily worked, saving the engineman a great deal of fatigue.

The tender of this engine, exhibited with it, has six wheels, and weighs empty 9½ tons, full 17½ tons, the load being equally distributed on the wheels. It is fitted with the apparatus for picking up water whilst running, as described at a former meeting of the Institution (see Proceedings Inst. M.E., 1861, page 43): a scoop is let down from the bottom of the tender, and dips into the water contained in a long open trough between the rails, from which it is made to flow up the scoop into the tender tank by the motion of the tender in running. A minimum speed of more than 15 miles per hour is required for this operation. Three of these water troughs have now been laid down and are in use in different situations on the London and North Western Railway; and their advantages are that the size and weight of the tender for running a given distance may be reduced, the number of stoppages lessened, and time saved. An express engine has thus been enabled to run the whole distance from Holyhead to Stafford, 130½ miles, in one continuous run, without a single stoppage, at an average speed of 54½ miles per hour.

The next engine to be noticed is a Passenger Express engine, for the South Eastern Railway of Portugal, 5 feet 5¾ inches gauge, exhibited and manufactured by Messrs. Beyer Peacock and Co., whose design is characterised by elegance, thoroughness, and finish, in form, arrangement, and detail. This engine is a type of the prevalent style of English inside cylinder express engines. The framing is composed of two pairs of longitudinal bars or slabs running straight from end to end, cross-braced by the cylinders, the footplate, and various cross plates. The extension alongside the firebox of the two inside longitudinal slabs, which stopped short in front of it in the earlier examples of this description of frame, is a great improvement in practice, as it connects the steam cylinders, driving axle, and drawplate directly and immovably together, and bears the entire strain of the steam in the cylinders and transmits the tractive force to the train. The boiler is thus relieved of all strain from the working parts, from which formerly it was not free and then suffered accordingly. The driving axle is made with only two bearings, inside the wheels, for which the guards are forged on the inside frame plate, and the leading and trailing wheels have their bearings outside the wheels; an arrangement originated by the late Mr. John Gray, and now generally adopted for its simplicity, and for the greater firmness of the frame and the increased duration of the crank axle. The steam strain is in fact confined to the two inside frame plates, and to the inside bearings of the crank axle, close to the cranks. The leading and trailing wheels are 3 feet 9 inches diameter, the driving wheels being 7 feet: the leading wheels have been thought rather too small, and no doubt there is space in the engine for enlarging them; but they would have departed from uniformity with the six tender wheels, which also are 3 feet 9 inches diameter.

The short cast iron blast pipe reaching just above the level of the upper row of the tubes is to be remarked. This level of blast orifice has been found to give the best results, creating a better draught with a wider orifice, as compared with higher blast pipes; and was arrived at by Mr. Peacock, by means of a series of well arranged experiments on the Manchester Sheffield and Lincolnshire Railway: the low blast pipe is now generally employed. The early blast pipes were carried some distance into the chimney and had very contracted orifices, and a sharp blast with much back pressure on the piston was the consequence.

The boiler, in consequence of the greater width of the Portuguese gauge, 5 feet 5¾ inches, has a large square firebox, 4 feet 10 inches each way over the outside shell; and has a large diameter of barrel, 4 feet 2 inches, which gives abundance of steam and water space.

Nevertheless for effective heating surface a firebox of oblong form would in the writer's opinion be better. There are 215 tubes of 2 inches diameter placed at ·56 inch apart: had the tubes been only 1⅞ inch diameter, which upon the whole the writer considers the best size, and placed in the same position, the larger clearance of ·69 inch so obtained for circulation would have improved the evaporative efficiency. The firebox is adapted for coal burning with a firebrick arch, a deflector plate from the doorway, and sliding firedoors, on the plan in use on the Midland Railway (see Proceedings Inst. M.E., 1860, page 147).

A Passenger Express engine for the Caledonian Railway, exhibited and manufactured by Messrs. Neilson and Co., is a specimen of the class of engines extensively used on that line, which were designed with a view to economy rather than speed, although a very large driving wheel is used; they are employed on main line service between Glasgow and Carlisle, taking their turn with all trains, fast and ordinary. From the experience that had previously been acquired of the durability and general economy of the 7 ft. driving wheels over the original 6 ft. wheel passenger engines of the line, it was supposed that a further extension of the principle of enlarging the driving wheel would be advantageous; and the extreme size of 8 feet 2 inches diameter has been adopted for trial in the class of engines exhibited: but it may be questioned whether this has not been carried too far. The cylinders are 17¼ inches diameter and 24 inches stroke. This engine has grown out of the old Crewe pattern of engine, originally introduced on the Caledonian line by the late Mr. Locke, the chief engineer, and successively modified to meet the growing requirements of the traffic. The engine weighs in working order 30¾ tons, of which the driving weight amounts to 14¼ tons. This driving weight is considerably in excess of any other among the engines exhibited, except that of the North Western inside cylinder engine; but no doubt the large size of the driving wheels, 8 feet 2 inches diameter, reduces in some degree the injurious effects of so great a concentrated load on the permanent way. The counterweights are compactly forged into the rims of the wheels, extending over one third of the circumference; and though a little more weight is thus requisite to complete the balance, it sweeps gently over the rails when the engine is in motion, without the sledge-hammer effect of a revolving cubical mass compressed into the space between two or three spokes. For such a large wheel also the spokes are planted thickly, at 10 inches centre to centre on the rim: the stiffness of a spoke decreases in a rapid proportion with its length, diminishing as the cube of the length, so that a spoke of an 8 feet wheel will be only about half as stiff as a spoke of the same scantling for a 7 feet wheel. The driving axle is of cast steel and the tyres are of Krupp's steel.

The framing of the old Crewe engine is retained in this one, giving outside bearings to the fore and hind axles and inside bearings to the driving axle. In this respect the North Western outside cylinder engine already described is at variance with the older practice, having but one longitudinal frame plate on each side, with inside bearings for all the wheels. It may very properly become a question whether the cylinders should be so rigidly united as they are in the Caledonian engine to the outside frame plates, which carry two pairs of wheels and axles and of course transmit the shocks of the road to the cylinders. The footplate is provided with a housing for the engineman and stoker, a most important provision for their comfort and consequently for the safety of railway trains. Plain fence plates or weatherboards across the back of the firebox are now commonly applied to engines, and these are useful; but the housing is certainly better, and it seems strange that the adoption of so desirable a protection should have been so long neglected.

The slide valves are made with 1⅛ inch lap at each end, according to the proportion originally arrived at by Mr. Sinclair on the Caledonian Railway from finding the peculiar importance of long lap and long travel for the valves of outside cylinders. The long lap and long travel of the valves unquestionably facilitate the free exhaust of the steam at high speeds from exposed cylinders, in which the steam is more or less partially condensed: and moist steam being not so active as dry steam exerts an excessive back pressure on the piston, if not freely discharged.

The boiler is fitted with the firebrick arch and door deflector previously referred to for burning coal; the barrel is 3 feet 10 inches diameter, and contains 192 tubes of 1⅞ inch diameter, placed with ·62 inch clearance between them. Giffard's injectors are employed. The consumption of coal by these engines is stated to average 23 lbs. per mile, with trains of 9 heavy carriages and a speed of 35 to 40 miles an hour; and they take 14 loaded carriages up the Beattock Incline, an average rise of 1 in 78 for 10 miles, at a speed of 30 miles an hour.

The Goods engine for the London Chatham and Dover Railway, exhibited and manufactured by Messrs. Sharp Stewart and Co., is a first-rate six-coupled-wheel engine, with 5 feet wheels and 17 inch cylinders of maximum power, adapted for the heavy loads, heavy gradients, and the high speeds ultimately intended on that line. It is a fine engine, of excellent workmanship and proportions. It weighs empty 28½ tons, full 32 tons; and the weight is nearly equally distributed over the three axles, to the advantage of the permanent way, so that the load on any one axle does not vary more than ⅞ ton from the average load on all the axles, the loads being as follows:—

Leading wheels	10·65	tons.
Middle wheels	11·55	„
Trailing wheels	9·85	„
Total weight .	32·05	„

The firebox is 8 feet long externally, with an inclined grate on the South Eastern Railway plan for burning coal, as shown in Figs. 3 and 4, Plate 21, which give a longitudinal section and sectional plan of the firebox. The hind axle is thus brought under the firebox about one third of the length, and is enabled to take its proper share of the load; whilst the length of wheel base is moderated, and is bisected by the middle axle: advantages peculiar to this plan of firebox. The firebox measures 7 feet 3 inches long inside, divided longitudinally by a midfeather, as seen in the plan, Fig. 4; and has 27½ square feet of grate. There are 189 tubes, 2 inches diameter, with ·62 inch clearance, within a 4 ft. 2 ins. barrel. These are good proportions, according to current practice; but had there been only 160 tubes with ·75 inch clearance, in such a large barrel, it would in the writer's opinion have been decidedly better. The boiler is fitted with Giffard's injector. The housing for the engineman, with windows in the front and sides, is very good and complete.

The frame is composed of four longitudinal plates, carried from end to end, with suitable cross plates to bind them. The outer plates are each of one slab, combining great strength and lightness; the usual construction of outer frame with double plates and timber packing has thus been superseded in this engine. The driving axle has four bearings, two inside and two outside, and the extreme axles have only outside bearings; and the old antagonistic action is set up, arising out of the unequal wear of the inside and outside bearings: the inside bearings next the cranks, receiving the full strain of the steam, will wear faster than the outside bearings, leaving the cranks unsupported, and shortening the duration of the axle; overstraining in that way also the connexions of the inner and outer frame plates, and thereby loosening them. On the other hand this arrangement admits of large outside bearings and capacious axleboxes for all the axles; an advantage which unfortunately the narrow gauge does not permit for inside crank-axle bearings. The drawing tackle of this engine is connected exclusively to the frame, and kept quite independent of the firebox.

The valve gear is very substantially and firmly arranged: the expansion link is shifted, and the slide block is not overhung, but hung between the ends of the link which carries it. This engine is stated to be capable, with a working pressure of 120 lbs. per square inch, of taking a load of 480 tons on a level at 20 miles an hour, or a load of 250 tons up a gradient of 1 in 100 at 15 miles an hour.

A six-wheel-coupled Goods engine of excellent workmanship for the Midland Railway was exhibited and manufactured by Messrs. W. Fairbairn and Sons. It has the ordinary rectangular firebox with 14½ square feet of grate, and is fitted on the Midland plan already referred to for burning coal. The cylinders are 16 inches diameter with 24 inches stroke. The engine weighs in working order 32¼ tons, and is a thoroughly good engine of its kind; it is a type of the powerful goods engine usually met with on the old main lines of railway, and may be usefully compared with the Chatham and Dover goods engine last described, which is an engine of the same weight and power, but of a different and more recent class. In the first place, the weight is not so well distributed on the wheels of the Midland engine, being considerably in excess on the leading wheels, the loads being as follows:—

	Midland engine.	Chatham and Dover engine.
Leading wheels	12·30 tons	10·65 tons.
Middle wheels	11·25 „	11·55 „
Trailing wheels	8·70 „	9·85 „
Total weight	32·25 „	32·05 „

showing in the former engine 3½ tons more load on the leading wheels than on the trailing, and in the latter only ¾ ton more; while the wheel base of the former engine is 16 feet 6 inches, or 1 foot more than that of the latter, as the vertical firebox of the former keeps back the hind axle. The frame of the Midland engine, like that of the other, has four longitudinal plates, with four bearings to the driving axle and outside bearings to the other axles; but the inside frame plates stop short at the firebox, and are fastened to it by sliding joints, allowing for expansion of the boiler. The drawplates are rivetted to and across the back of the firebox, from which the whole of the drag is taken; and therefore, as the tractive force must be transmitted from the outside frame plates to the firebox, they are very strongly united to it by brackets for that purpose. Thus the whole area of the frame behind the firebox remains unemployed except as standing ground. This is in the writer's opinion an objectionable feature in the engine, without any countervailing advantage. Not only is the steam power transmitted circuitously, tending to overstrain and buckle the framing; but it arbitrarily subjects the boiler, already highly strained, to a great and unnecessary additional strain, which is now beneficially avoided in the other arrangements of the framing as already described.

The boiler tubes are well designed, being 2 inches diameter, 180 in number, and placed with ·62 inch clearance, in vertical rows; which accounts for the high character of these engines for keeping up the steam. The boiler is put together without angle iron, the plates being flanged at the end; the steam dome also is flanged and formed in one piece. For this purpose thick-edged plates are used, rolled to ⅝ inch or ¾ inch thick at the edge, to allow material to work upon in flanging. The advantages claimed for the thick-edged plates in their application are that they save a joint, including a row of rivets, and are stronger than angle iron joints; and that the joints are cheaper and easier to make, and are not subject to grooving by corrosion. The dome joints being faced in the lathe, bad joints are prevented.

Of the Mixed engines a six-wheeled four-coupled engine for the East Indian Railway, of 5 feet 6 inches gauge, was exhibited and manufactured by Sir W. G. Armstrong and Co., with outside cylinders and the hind wheels coupled. The wide Indian gauge of rails, 5 feet 6 inches, admits of a large firebox 4 feet 1½ inches square inside, with a grate of 17 square feet, which appears too large for the cylinders of 16 inches diameter and 22 inches stroke and the wheels of 5 feet 7 inches diameter. The boiler tubes 157 in number are 10 feet 11 inches long, 2¼ inches outside diameter, and they clear one another by ·56 inch. These proportions would in the writer's opinion be improved by reducing the tubes to 2 inches diameter with increased clearance; and the reduction of heating surface would be amply compensated by the increased facility for circulation of the water and steam between the tubes.

The total weight of the engine in working order is 32¾ tons, which is too great for such an engine; 21¼ tons are available for adhesion, but very unequally divided between the wheels, the respective weights being

Leading wheels	11·47	tons.
Middle wheels	12·55	„
Trailing wheels	8·67	„
Total weight .	32·69	„

The leading wheels are 3 feet 7 inches diameter, and the six wheels of the tender are 3 feet 9 inches diameter, only 2 inches difference in size.

The slide valves have only ¾ inch lap, but this is inadequate for a 16 inch outside cylinder, in which there is always more or less condensation of steam. The back pressure on the piston at high speeds must be considerable, as an insufficient lap prevents a full and free opening to the exhaust, which is required to be greater for moist than for dry steam. The footplate is furnished with an awning frame, to protect the engineman completely from the sun and to ensure ample ventilation: an object of vital importance in India. It is a very complete screen, the use of a weatherboard being unfavourable for ventilation.

A Mixed engine was exhibited by the Great Eastern Railway, manufactured by Messrs. Robert Stephenson and Co., with six wheels, four coupled, and outside cylinders. The framing has but one longitudinal plate on each side from end to end, with inside bearings for all the wheels. With 17 inch cylinders and 6 ft. 1 in. driving wheels, which are more powerful than in the East Indian engine, the boiler is lighter, having only 13½ square feet of grate instead of 17 square feet, with a shallower firebox and a smaller barrel. Hence the total weight of the engine is less, and the weight is more equally distributed on the wheels, the loads being

Leading wheels . . .	11·10 tons.
Middle wheels . . .	10·70 „
Trailing wheels . . .	10·05 „
Total weight .	31·85 „

The leading wheels of 3 feet 7 inches diameter are also very properly made uniform with the six tender wheels. The engine is reported to have run 45,000 miles without repairs; for which satisfactory result it is indebted to excellent design and workmanship, and no doubt also to the favourable distribution of the weight, and to the material of the tyres, Krupp's steel, which were apparently very little worn. A pair of tyres which had run 68,000 miles showed a wear of only about ¼ inch on the tread. Several of the driving and trailing wheel tyres of engines of the same class have run 60,000 to 70,000 miles without re-turning. The duration of these steel tyres is estimated at 100,000 miles on the leading wheels, and 150,000 miles on the middle and trailing wheels; but none have yet been worn out.

The barrel of the boiler is 3 feet 10 inches diameter, and has 192 tubes, 1⅞ inches diameter, with ·62 inch clearance; which are fair proportions. The firebox is fitted for burning coal, with a door deflector and jets of steam from the sides of the firebox. The slide valves have 1¼ inch lap, with 5⅛ inches travel in full gear: very suitable proportions for outside cylinders as before observed, for quick running and free exhaust.

Engines of this class are stated to work passenger trains averaging 16⅛ carriages, maximum load 35 carriages, at an average speed of 25 miles an hour, consuming 25 lbs. of coal per train mile; and goods trains consisting of 35 wagons, gross weight 300 tons, at an average speed of 20 miles an hour, consuming 30 lbs. of coal per train mile.

Of the Tank locomotives the largest is that exhibited and manufactured by Messrs. G. England and Co., weighing 17 tons in working trim. It was designed for branch lines, and has six wheels with a 10 feet wheel base, four coupled wheels of 4 feet diameter, and cylinders 11 inches diameter. It is neatly arranged, with two tanks to hold 520 gallons very conveniently placed on the footplate, one on each side, enclosed out of view by a fence carried nearly from end to end of the engine. Of the weight, which is equally divided on the axles, two thirds is available for adhesion. There are 153 boiler tubes, 1¾ inch diameter, with ·50 inch clearance, the boiler barrel being 3 feet 8 inches diameter.

A neat compact and serviceable little Tank engine was exhibited and manufactured by Messrs. Manning Wardle and Co., specially adapted and extensively used for collieries, ironworks, and public works. This engine was employed at the Exhibition under the author's superintendence in conveying the machinery on trucks from the unloading cranes to its destination in the western annex along lines of rails laid down for the purpose; a duty in which it was of essential service. It has 9 inch outside cylinders, and four wheels coupled of 2 feet 9 inches diameter, on a wheel base of 4 feet 9 inches. The area of firegrate is nearly 5 square feet; and the boiler has 55 tubes, 2 inches diameter, with ·69 inch clearance, which is amply sufficient for circulation. The weight in working trim is 10½ tons, equally distributed over the two pairs of wheels. The water tank is placed upon the barrel of the boiler, and holds 252 gallons. The coke boxes hold 7½ cwts. Giffard's injector is employed. With a working pressure of 120 lbs. per square inch in the boiler, the exhibitors assume an effective mean pressure of 60 lbs. in the cylinders, which appears too low but errs on the safe side; upon this they estimate the extreme tractive power as equal to moving 206 tons, but the actual power of the engine is no doubt greater.

The last and the smallest locomotive exhibited in the English section is a Tank engine for ironworks and collieries in South Wales, manufactured by the Neath Abbey Iron Co., for a gauge of 2 feet 8 inches, with 8 inch cylinders and four coupled cast iron wheels of 2 feet 4 inches diameter, 4 feet apart centre to centre. The centre of the boiler is only 2 feet above the rails. The boiler has 3½ square feet of grate, and 59 tubes, 1½ inch diameter and 6 feet long, giving a total heating surface of 181 square feet; the gross weight in working order is 6·85 tons. The tank is on the back of the boiler. The engine is carried on volute springs. The engines employed in the Neath Abbey Works have a run of nearly one mile, with gradients varying chiefly from 1 in 15 to 1 in 26, with a small portion 1 in 100; they take the return empty wagons up the incline to the coal pits, the full ones going down by themselves. With 80 lbs. pressure of steam the regular duty of the engine is to take up 16 empty wagons or trams, weighing altogether 6·45 tons or nearly the weight of the engine itself, in 7 minutes, or at the rate of 8 miles an hour. With 66 lbs. steam it can take up at the same speed 12 wagons weighing 4·50 tons.

Foreign Locomotives.—The Foreign locomotives exhibited were all made for the English 4 ft. 8½ ins. gauge.

The French department contained examples and designs of various classes of engines, some of them not known in this country. The first is an ordinary Passenger engine exhibited and made by the Orleans Railway. It has outside cylinders, with the valves and valve gear outside the cylinders and crank-pins. The firebox is constructed for burning coal, with a long sloping grate, and a transverse water partition or midfeather across the firebox, above and nearly parallel to the grate, extending backwards from the tube plate and similar in position to the firebrick arch used in English engines, so as to deflect the flame towards the firedoor and cause it to meet the air admitted there. These are merely varieties of English practice: but the outside gearing is objectionable, for besides being exposed to accident the play of the parts arising from wear injuriously affects the working of the valves in regulating the distribution of the steam, to a much greater extent than when the valve gear is inside the wheels. Giffard's injector is applied, the construction being simplified by omitting the mechanism for varying the supply of water. The axles are lubricated from below by means of cotton stumps, which lift the oil by capillary attraction from a reservoir in the bottom of the axlebox.

A six-wheel-coupled Goods engine for the Orleans Railway was exhibited and made by Messrs. Cail and Co. It has inside cylinders, with 5 ft. wheels and a wheel base of 11 feet 4 inches. It had already run 13,000 miles on the central division of the railway, where the curves are numerous and sharp and the inclines steep. The fore and hind axleboxes have ¾ inch play transversely, and are held taut by springs acting horizontally, which tend to restore them to their central position. The wheels are solid wrought iron, of excellent workmanship, welded at two heats on Arbel's plan. The rim is forged in segments, the nave in two circular halves, and the spokes are let into the rim segments and the two halves of the nave. The whole is clamped together, heated in a furnace, brought out and placed under a large hammer with suitable dies the size of the wheel, and welded on one side. The partially formed wheel is again heated, and welded complete on the other side. A first-rate piece of work can be done by this process. The counterweights are welded to the rim and spokes of the wheels. The connecting and coupling rods are of cast steel.

The Northern Railway of France exhibited the "Dromadaire" heavy Tank engine, shown in Figs. 5, 6, and 7, Plates 22 and 23. The object specially aimed at in this engine was to obtain a considerable supply of steam and great tractive power, in combination with the smallest possible weight. For this purpose the firebox, as shown in the transverse section, Fig. 6, Plate 23, is placed above the wheels and frame plates, in order to allow of greater width, a larger grate, and more tubes than when at the usual level, without lengthening the boiler. Eleven such engines are at work on the Northern Railway of France, burning coal slack. The roof of the firebox and its shell are flat and parallel, and stayed together like the sides, Fig. 6. The steam space in the barrel is reduced to make room for the tubes, and is supplemented by a tubular steam chamber A above the boiler, as shown in the transverse section, Fig. 7, containing 19 iron tubes, 3⅛ inches outside diameter and ⅛ inch thick, giving 129 square feet of drying surface, which is not included in the total heating surface of 1667 square feet stated in the table appended; through these tubes and also round the steam chamber the heated gases from the smokebox pass back to the chimney B for drying the steam. The chimney B is laid horizontally, in continuation of the annular space which surrounds the steam chamber A, since the great elevation of the boiler, nearly 8 feet from the rails to the centre of the barrel, prevents the chimney being placed vertically with sufficient length.

This heavy-gradient locomotive has eight wheels, 3 feet 6 inches diameter, all coupled, on a base 12 feet 6 inches long; and two cylinders, 18·9 inches diameter and 18·9 inches stroke. It has 28 square feet of grate, and a total heating surface of 1667 square feet, having 356 tubes of $1\frac{9}{16}$ inch diameter. The engine weighs in working order 42¾ tons, equally distributed, giving 10 to 11 tons load on each pair of wheels.

A drawing was also exhibited of the Passenger Tank engines for heavy gradients working on the Northern Railway of France, in which the ordinary coupling of wheels is dispensed with, and four 14¼ inch cylinders with 13⅜ inches stroke and 5 ft. 3 ins. wheels on two independent axles are employed. One pair of cylinders and wheels is placed at each end of the engine, with small intermediate carrying wheels 3 feet 6 inches diameter, on a wheel base of 17 feet total length.

A second drawing was shown of the four-cylinder Goods Tank engines employed on the same railway, with six pair of wheels 3 feet 6 inches diameter, coupled in two sets of three, each pair of cylinders working three pairs of coupled wheels: the wheel base is 19 feet 8 inches long, and the fore and hind axleboxes have 1¼ inch play transversely to admit of running round quick curves of 600 feet radius. The cylinders are 16⅛ inches diameter with 17¼ inches stroke, and the boiler contains 464 tubes $1\frac{9}{16}$ inch diameter. The weight of the engine is 41 tons empty, and 57 tons full, equally distributed, giving 9 to 10 tons on each pair of wheels.

In the "Dromadaire" and the two other kinds of engine exhibited in drawings by the Northern Railway, the cylinders are outside, and the valve gearing outside them and overhung, which is, as already remarked, the most unfavourable position of gearing for continued accuracy of working. The weight of these engines is top-heavy; and for a run of 230 miles, the length of the line, they cannot well be worked with safety at the occasional high speeds demanded by a large traffic on a long line. The calculations of the capacity of the engines have been based on heating surface as such, which has been assumed to be synonymous with evaporative power. It must be remarked however that there is only ·44 inch clear space between the 356 tubes of the "Dromadaire," and only ·56 inch between the 464 tubes of the four-cylinder goods engine: proportions utterly inadequate to maintain an effective circulation and evaporating action on every unit of surface. There can be no doubt that half the number of tubes properly placed would have answered the purpose decidedly better. The best thing about these engines is the uniform distribution of the weight, giving great tractive power without distressing the road on the straight portions; but the wheel base is impracticably long in the four-cylinder engines, and must greatly strain the engine and road as well as add to the resistance on sharp curves. The proportion of the tractive power, taking the effective mean pressure in the cylinders at 80 per cent. of the boiler pressure for low speeds, is about one sixth of the weight for adhesion; which is a fair proportion and utilises the immense weight of the engine.

The designs of an "articulated" Tank locomotive of great power, like what is known in England as a bogie engine, are exhibited in the French department by Messrs. Meyer of Vienna, one of whom is the inventor of the well known variable expansion gear. On many railways an adhesion weight of 40 tons has now become insufficient, and the necessity for constructing railways cheaply has led to the adoption of steep gradients and quick curves; so that the engines adapted to work these lines must have in certain cases 50, 60, and even 80 tons adhesion weight, with the means of bending or fitting the engine to the curves, since the practice of using assistant engines or separating the trains into two or more parts in particular situations is objected to as inconvenient and costly. This engine has a single long boiler of large dimensions, as shown in the side elevation, Fig. 8, Plate 24, mounted on two separate carriages, with a swivelling connexion, each having its own separate pair of cylinders working six coupled wheels placed near together; so that the engine, although of great total length, could readily pass round very sharp curves, whilst the whole of the weight is made available for driving adhesion.

The boiler rests on the front bogie frame by a hollow ball-and-socket pivot C at the centre over the middle axle, as seen in the longitudinal section, Fig. 9, Plate 24, and the sectional plan, Fig. 10, Plate 25; and on the back bogie frame by two hemispherical bearings DD on the frame, one on each side of the firebox, as seen in the side elevation, Fig. 8, and the plan, Fig. 10. The boiler thus rests on three points, whilst the two bogie frames are each free to follow the curves and irregularities of the road by swivelling under the boiler, as shown by the second plan, Fig. 11, which represents the engine on a sharp curve, the centre line of the boiler being indicated by the strong dotted line E. The hemispherical bearings DD at the sides of the firebox have a limited play, sliding fore and aft to suit the changing position of the boiler relatively to the hind bogie frame. The middle pair of wheels in each bogie have a considerable amount of transverse play allowed them, so as to move laterally in running round sharp curves, as seen in the plan, Fig. 11. The two bogie frames are connected by a single strong coupling rod F, having spherical bearings at each end.

The whole of the cylinders, valves, and other mechanism is outside the wheels. The steam from the boiler is conveyed to the two pairs of cylinders by the connecting pipes G with flexible joints, shown in the side elevation, Fig. 8, and transverse section, Fig. 12; and the exhaust steam from both pairs of cylinders is carried up into the smokebox by the exhaust pipe H through the centre of the hollow pivot C, Fig. 9, the exhaust from the hind bogie communicating with that of the front by means of the flexible connexion I, Figs. 9 and 11.

The distribution of weight on the two bogie frames is such that the centre of gravity of each of the two portions of the load is at the centre axle. The water tanks JJ are in front, and the coal boxes K behind, Figs. 8 and 9, Plate 24. The total weight of 60 tons is available for adhesion, 10 tons on each axle. Each bogie frame stands on a wheel base of 8 feet 6 inches, and the centres of the two bogies are 22 feet apart. The wheels are 3 feet 10 inches diameter, and the cylinders 17½ inches diameter with 19¾ inches stroke. The tractive power is estimated at 22000 lbs., nearly one sixth of the weight, so as to take a gross weight of 2300 tons including the engine at 10 miles an hour on a level; and 340 tons up an incline of 1 in 40 or 155 tons up 1 in 17 at the same speed.

This plan of locomotive affords in the writer's opinion the most satisfactory solution yet given of the problem of obtaining a goods engine of maximum power. With independent bogie frames, each having its own separate pair of steam cylinders, a mass of coupling rods and parallel motions is got rid of, and the resistance of the engine is materially reduced in its working parts and in passing along curves, leaving an important balance of power for useful work.

In the Belgian department is one six-wheel-coupled inside cylinder Goods engine for the Belgian State Railway, made and exhibited by the Société Anonyme de Couillet. This engine is shown in side elevation in Fig. 13, Plate 26. The firebox, shown in longitudinal section in Fig. 14, is a reproduction of the English one previously described in the Chatham and Dover engine, with a long inclined grate, but without the longitudinal water partition. This firebox affords the same advantage in admitting the hind axle below it, giving a moderate wheel base, in this instance 13 feet 1 inch; and equalising the distribution of the weight on the wheels, the loads being as follows:—

Leading wheels . . .	11·00 tons.
Middle wheels . . .	11·45 „
Trailing wheels . . .	11·00 „
Total weight .	33·45 „

The connexion of the machinery and framing in this engine is in the writer's opinion radically wrong. The three axles each have two outside bearings, carried by two single outside frame plates; and the cranked axle has only one additional bearing 4½ inches long, placed in the centre between the cranks. This single narrow bearing compressed between the two cranks must receive the entire fore and aft strain of the steam pressure; whilst the outside bearings more than 6 feet apart are 7 inches long, and can receive very little of the fore and aft thrust and pull while the middle bearing is new. But as the middle bearing must prematurely wear loose, the greater part of this strain will then be thrown upon the outer bearings 6 feet apart; and this, acting in addition to the strain arising from the loads on the bearings outside, will be likely to break the axle. Again the fastening of the cylinders to the frame is effected through the valve chests, which are exterior to the cylinders, in two castings spanning the space of 6 feet between the frame plates: an arrangement which, unless the cylinder castings are made exceedingly strong and heavy, will likewise overstrain and break the connexions. On the other hand by devoting to the valve gear and eccentrics the space on the cranked axle that is usually occupied by the inside bearings, the valve motion is very conveniently accommodated; and probably this slight advantage was the inducement to depart from the usual and indispensable application of inside bearings at the wheels.

The Austrian State Railway exhibited a Passenger Express engine, the "Duplex," shown in Figs. 15 and 16, Plates 27 and 28, having four cylinders and four cranks on a single driving axle, specially designed for steady running at high speeds. The usual counterweights in the driving wheels are here superseded and the reciprocating and working parts are made to balance each other by placing a pair of outside cylinders L L side by side and connecting them to a crank and return crank M, Fig. 16, opposed to each other, on each side of the engine; so that the two pistons on each side and all their connexions move in contrary directions and balance each other's inertia. The cylinders L L, shown enlarged in Figs. 17, 18, and 19, are 10⅞ inches diameter, with 24⅞ inches stroke, and 6 ft. 9 ins. driving wheels.

There can be no question that this system is perfectly successful in effecting the object in view; and had it been brought out twenty years ago, it would no doubt have been highly appreciated. But as the balancing of engines with two cylinders has for the last ten years been completely accomplished for all practical purposes by means of counterweights, the use of four cylinders as in this engine is not likely now to become popular; unless indeed railway companies in the race of competition should aim at excessive speeds of 80 or 100 miles an hour.

The Austrian State Railway also exhibited the "Steierdorf," a heavy Tank engine with five coupled axles, shown in side elevation and plan in Figs. 20 and 21, Plates 29 and 30. The boiler rests on two frames coupled together by a pivot bolt N. The steam cylinders L are fixed on the front frame, and the tank J on the hind frame; and the three pairs of wheels of the front frame are coupled to the two pairs of the hind frame by means of an intermediate shaft O and radiating parallel motion P, shown enlarged in the transverse section, Fig. 22, Plate 31. This intermediate shaft O is ingeniously contrived to adapt itself to the varying angularity of the hind frame on curves, and at the same time to continue to transmit the power from the first to the second frame, as shown by the plan, Fig. 23, Plate 31, representing the position of the several coupling rods when the engine is on a curve. The intermediate shaft O has overhung cranks on each end and is carried on spherical bearings by the distance pieces R, Fig. 22, on the front axle S of the hind frame; it is also kept at a constant distance from the hind axle T of the front frame by the distance links U, Fig. 20, having spherical bearings at both ends; and the cranks of the intermediate shaft O are connected to those of the axles S and T by the coupling rods V and P, all of which have spherical bearings at both ends. The relative positions of the three axles being thus fixed, the power is transmitted from the hind or driving axle T of the front frame, through the coupling rods P to the cranks on the intermediate shaft O, thence by the coupling rods V to the outside cranks on the front axle S of the hind frame, and further by coupling rods to the hindmost axle. The wheels are 3 feet 3½ inches diameter, the cylinders 18⅛ inches diameter with 24⅞ inches stroke, and the total weight in working order is 46 tons. The firebox made for burning coke has 15 square feet of grate; and the boiler contains 158 tubes $2\frac{1}{16}$ inches diameter, with ·69 inch clear space between them.

In the Prussian department one engine was exhibited by Mr. A. Borsig of Berlin. It was a six-wheel four-coupled engine, with outside cylinders 17 inches diameter by 22 inches stroke, and driving wheels of 4 feet 6 inches diameter, the hind wheels being coupled, and all the axles being between the firebox and smokebox. This type of engine is exclusively employed on the Minden and Cologne Railway for mixed and goods trains; and also on many other German railways. The free use of steel in the construction of this engine confers on it an air of lightness, perhaps too great lightness, which contrasts strongly with the heaviness of the tender.

The proportions of the boiler are good; and this circumstance, in addition to the very excellent and well finished work, may account for the popularity of that class of engine: but it has some grave defects which must detract from its usefulness. The suspended weight is carried on three points, by a cross spring over the leading axle and compensating or equalising levers connecting the springs of the two driving axles on each side of the engine. This notion of a triangular elastic bearing with the apex in front, much thought of at one time, is now nearly discarded in England, on account of its giving the engine a dangerous freedom of movement at high speeds.

The cylinders are fitted with double valves for variable expansion, the expansion valve being on the back of the other, with a central passage for steam through it: the lower or leading valve is worked by a link motion in the usual manner; and the upper valve by a separate rod from the fore eccentric working in a grooved sector, from which a variable travel and cut-off are communicated to the valve.

The steam port opens for the exhaust at 90 per cent. of the stroke for all degrees of expansion, and is only opened 3-8ths inch for the exhaust when the piston arrives at the end of the stroke; and as the steam ports are very small in area, each being only 1-20th the area of the piston, there can be no doubt the back pressure is very considerable in consequence, and more particularly with an outside cooling cylinder. For a 17¼ inch outside cylinder in the Caledonian engine previously described the area of steam port provided is 1-11th that of the piston, whilst the valve is open full port for the exhaust when the piston reaches the end of the stroke. Moreover it is not good practice to keep the same point of the stroke for the exhaust under all degrees of expansion; high expansive working usually accompanies high speeds, and therefore the exhaust should be made to open earlier in the course of the stroke for the higher grades of cut-off, in order to give the steam greater liberty for escape before the piston returns upon it. These conditions of the good working of steam are comprehended in Stephenson's expansion link motion, and are now thoroughly appreciated and established in English practice; and the other attempts at expansive valve motion for locomotives have been abandoned in this country.

In employing steel for the working parts of this engine, such as the piston rods, the connecting and coupling rods, and the crank pins, the dimensions of the wearing surfaces have in some cases been reduced. The bearings of the coupling rods are reduced in proportion to the size of the rods; though it is reasonable that as the strains remain the same the sizes of the wearing surfaces should not be altered. The axleboxes are of wrought iron.

In the Saxon department a six-wheel four-coupled engine was exhibited by Mr. R. Hartmann of Chemnitz, specially designed to work in mountainous districts. It is in fact a bogie engine, having four coupled wheels 4 feet 6 inches diameter with 21 tons on them for adhesion, and a swivelling truck on Bissell's plan in front with 7 tons load, making a total of 28 tons. The cylinders are 15 inches diameter by 22 inches stroke; and are outside, with outside valve gearing, as is so prevalent a custom on the continent. The framing has two longitudinal plates 8 inches deep and 1⅛ inch thick, to which the cylinders are fixed, with 16 inches of overhang. This is an excessive overhang upon so narrow a frame plate, and the valve gear being still further overhung the valve hops about at every stroke as the axleboxes wear. Overhung eccentrics for valve gear outside the crank pin never do well for heavy work in consequence of the unsteadiness. The best feature in this engine is the swivelling truck with a triangular frame, which carries the fore part of the engine on one pair of wheels with a limited but sufficient allowance of lateral play, and radiates on a pivot behind it fixed under the boiler. With a flexible wheel base only 11 feet 9 inches long there is no doubt that in this engine and in others of ordinary size the Bissell truck is well adapted for leading round the quickest curves likely to be found in practice.

In the Italian department an inside cylinder six-wheel-coupled locomotive is exhibited from the Pietrarsa Royal Works, Naples, which is a creditable specimen of the old school of locomotive.

General Conclusions.—It appears that the requirements of continental railway traffic have demanded a greater variety of locomotive engines than has been found necessary in this country. Trains there are heavier; speeds are lower; and, more important than all, inclines are steeper. Whilst therefore the marks of progress in English engines are to be found mainly in refinements upon the original types, Foreign engineers have discarded our traditionary types and have originated novelties in every direction. In England engineers have arrived at higher speeds, with more powerful boilers and increased driving or adhesion weight.

The means of satisfactorily balancing the reciprocating and revolving machinery, the want of which was previously the bane of the outside cylinder engine, by counterweighting the wheels and steadying the engine, have been discovered and carried into practice since 1851; so that the outside cylinder engine properly balanced now runs even more steadily than the inside cylinder engine. Outside cylinders have consequently been employed for high speed and other duty with complete success: they have not however been employed for the heaviest work.

The inside cylinder is generally retained for six-wheel-coupled goods engines, and is not likely to give way to the outside cylinder for that class of work, on account of the objectionable construction involved by outside connecting rods combined with outside coupling rods for all the wheels. But for passenger traffic with four coupled wheels, and the lighter traffic of collieries and other private establishments, the outside cylinder is well suited and is extensively applied. It is however to be explained that the advantage of the six-wheel-coupled engine is limited to the old and the comparatively straight lines of railway, on which the destruction of cranked axles is not rapid and the wear and tear of tyres not severe. For lines with the prevailing sharper curves the four-wheel-coupled outside cylinder engine surpasses in efficiency and economy the six-wheel-coupled engine, running on curves with greater facility, utilising the adhesion weight better, and being subject to less wear. Hence the six-wheel-coupled engine with inside cylinders is to be found chiefly on the older and straighter lines. On the contrary the outside cylinders and the single and four-coupled driving wheels are to be found generally on the newer lines that have many quick curves.

In England the use of more than six coupled wheels in one engine has been avoided; three wheels coupled in one line are found sufficiently powerful and sufficiently troublesome, and it is preferred to supplement the power when necessary with an additional engine. On the continent however great efforts have been made to construct an efficient engine with great tractive force and enormous weight for adhesion, to ascend long and heavy inclines peculiar to mountainous districts. The subdivision and disposition of the weight in moderate loads on the rails has been effected with ease by distributing it over a sufficient number of wheels and axles. But the most important part of the problem has been to reconcile the unavoidable extension of wheel base in a straight line with the excessive curvature of the railways; for naturally, though unfortunately, heavy gradients and quick curves are generally to be found in company.

The system adopted on the Northern Railway of France, as shown in the side elevation of the "Dromadaire," Fig. 5, Plate 22, must fail to answer these requirements; for with a wheel base so extended the resistance of the engine itself must absorb a great proportion of the tractive power. A flexible wheel base is indispensable, and two ordinary engines connected together would work much more efficiently and economically than the vast masses actually employed. The opinion on the Northern Railway of France against the use of coupling rods in passenger engines, and the consequent substitution of two independent pairs of driving wheels with independent cylinders, must appear to be erroneous. The truth is that for working four driving wheels one pair of cylinders with coupling rods is the best method of providing adhesion weight; more especially since by the use of steel for the tyres their excessive and unequal wear and the consequent straining of the coupling rods are to a great extent prevented: at all events the wear of the tyres may be regulated and equalised, which removes the only objection worth consideration.

The Austrian plan of coupling over an extensive wheel base by a self-acting radial adjustment in the "Steierdorf," Plates 29, 30, and 31, is decidedly a better plan, and merits a thorough trial. There is nevertheless a complication of mechanism with many rubbing surfaces, liable to occasional overstraining, from irregular play of the bearings arising in wear in transmitting the power over a long distance through a flexible connexion; and engineers have to look in another direction for a comprehensive and satisfactory solution of the problem.

The plan of Meyer's engine appears in the writer's opinion to be the best yet brought forward for distributing steam power over a flexible train of coupled wheels, as shown in Plates 24 and 25. It is based on sound principles, as experience will no doubt prove. It is known that practically a locomotive boiler with ordinary management delivers a better supply of steam to a given pair of cylinders fully worked at a low speed of piston than at a high speed: the steam blows off from the boiler, and there is plenty to spare. By making the boiler a little larger therefore it is justly reckoned that steam can be supplied for four cylinders at a low speed, as well as for two; and the train of wheels is therefore divided into two independent groups under the boiler, each group free to adapt itself to the line of rails, and fitted with its own pair of cylinders and the necessary coupling rods, and receiving a separate supply of steam from the boiler. In short two steam bogies are employed, which carry the boiler and its accessories just as a load of timber is carried on a couple of swivelling trucks.

The abstract importance of heating surface appears to have been overrated, particularly by foreign engineers; and the primary importance of free passage for the currents of water in intimate contact with the heating surface, whether of the firebox or of the tubes, has been neglected. The width of the water spaces around the firebox has frequently been reduced to a minimum barely sufficient to preserve the plates from being overheated. The tubes have also been placed so near to one another and in such large numbers as totally to defeat their object of increasing the steam producing power of the boiler, because they have rendered it impossible for the water, crowded with globules of steam, to reach the surface of each tube and become evaporated. Tube surface under such circumstances is ineffective, and ultimately becomes mischievous; for the sediment deposited by water in boilers will, if not scoured out, coat the tubes and block up the spaces between them altogether. The greatest number of tubes known to have been applied in England is the 305 tubes of the Great Western express engine exhibited in 1851. In this engine the tubes, 2 inches in diameter, are placed only ·50 inch apart, and are not so effective for evaporation as the tubes of some of the earlier engines on that line, which were fewer in number but placed at from ·62 to 1·00 inch clear distance apart. In the English engines exhibited in 1862 the greatest number of tubes was 215 in Messrs. Beyer Peacock and Co.'s engine for the Portuguese gauge, with ·56 inch clearance; and 214 tubes in the North Western inside cylinder engine with ·50 inch clearance.

The best English practice exhibited in reference to the tubes is in the writer's opinion to be found in the North Western outside cylinder engine, the Caledonian, and the Great Eastern engines, all of which singularly enough have identically the same proportions; 192 tubes of 1⅞ inch diameter with ·62 inch clearance, placed in a barrel 3 feet 10 inches inside diameter. The excellence of these proportions is confirmed by the very satisfactory performances of the engines under very different circumstances.

The greatest number of tubes exhibited in the Foreign engines is 356 tubes with ·44 inch clearance, in the "Dromadaire" class of engines on the Northern Railway of France with the 4 ft. 8½ ins. gauge. The drawings of the twelve-wheeled four-cylinder goods engines employed on the same railway show 464 tubes with ·56 inch clearance; but these proportions will undoubtedly disappoint the expectations of the projectors, and the experience of a few years will, it is presumed, correct these abstract ideas.

The distinction between fireboxes for burning coal and those for burning coal-slack should not be overlooked. For coal 13 to 15 square feet of grate is sufficient; but for slack the North Western inside cylinder engine has 26 square feet of grate, and the Chatham and Dover engine 27½ square feet. The difference of fuel leads to a difference of treatment, inasmuch as special provision is made for the admission of air above the fuel for burning coal in pieces, in addition to the air that passes through the grate. For coal-slack no such provision is made; the layer of fresh fuel is thin, and a sufficient quantity of air is drawn through the large surface of grate. At the same time the slack is supplied in small quantities, and much more frequently than coal in pieces.

In placing the machinery on the frame it must be remarked that the foreign engineers seem to have merely shown how an inferior arrangement can be made to do. Next to excessive amount of heating surface their partiality is remarkable for overhung valve gearing upon outside cylinders, which is undoubtedly the worst possible position for efficiency and handiness of the engines.

Giffard's injectors have been extensively employed as a substitute for the ordinary feed pumps; and their general adoption in locomotive engines both in England and on the continent is an evidence of their popularity and general efficiency. The only apparent objection to the use of the injector is its inability to deliver heated water at a temperature of more than 120 degrees Fahr.; this prevents the use of means for heating the feed water by the contact or mixture of

Locomotives in International Exhibition 1862.

Name of Maker.	Name of Railway.	Description of Engine.	Total number of Wheels.	Gauge of Rails.	Firebox.			Tubes.						Total Heating Surface.
					Fuel used.	Area of Grate.	Heating Surface.	Number.	Outside Diam.	Clear space between.	Length.		Heating Surface.	
				Ft. Ins.		Sq. ft.	Sq. ft.	No.	Ins.	In.	Ft.	Ins.	Sq. ft.	Sq. ft.
L. & North Western Ry. Co.	L. & N. Western	Pass. Exp. (in. cyl.), single	6	4 8½	Slack	26·0	242	214	1·87	·50	9	4	980	1222
Do. do. ...	Do. do. ...	Do. (out. cyl.), do.	6	4 8½	Coal	14·9	85	192	1·87	·62	10	9	1013	1098
Beyer Peacock & Co.	S. East. Portugal	Passenger Express, do.	6	5 5⅔	Coal	18·0	101	215	2·00	·56	10	11	1238	1339
Neilson & Co.	Caledonian	Do. do. do.	6	4 8½	Coal	18·9	89	192	1·87	·62	11	5	1080	1169
Sharp Stewart & Co.	L. Chat. & Dover	Goods, six coupled	6	4 8½	Slack	27·5	120	189	2·00	·62	10	10	1072	1192
W. Fairbairn & Sons	Midland	Do. do.	6	4 8½	Coal	14·5	84	180	2·00	·62	11	9	1107	1191
Sir W. G. Armstrong & Co.	East Indian......	Mixed, four coupled	6	5 6	Coal	17·0	97	157	2·25	·56	10	11	1009	1106
R. Stephenson & Co.	Great Eastern ...	Do. do.	6	4 8½	Coal	18·5	72	192	1·87	·62	11	8	1105	1177
G. England & Co.	....	Mixed Tank, do.	6	4 8½	Coke	8·5	55	153	1·75	·50	8	5	645	700
Manning Wardle & Co. ...	....	Small Tank. do.	4	4 8½	Coal	4·9	30	55	2·00	·69	7	5	218	248
Neath Abbey Iron Co. ...	....	Colliery Tank, do.	4	2 8	Coal	3·5	37	59	1·50	·62	6	0	144	181
Orleans Railway Co.	Orleans	Passenger, single	6	4 8½	Coal	...	96	179	...	...	...		1046	1142
Cail & Co., Paris...........	Do.	Goods, six coupled	6	4 8½	Coke	14·6	88	187	2·06	...	14	5	1263	1351
Northern of France Ry. Co.	North. of France	Heavy Tank, eight coupl.	8	4 8½	Slack	28·2	109	356	1·56	·44	11	5	1558	1667
Société de Couillet	Belgian State ...	Goods, six coupled	6	4 8½	Slack	28·0	110	225	1·75	·62	11	6	1192	1302
Austrian State Ry. Co. ...	Austrian State...	Passenger Express, single	6	4 8½	Coke	15·0	84	160	2·06	·62	14	6	1260	1344
Do. do. ...	Do. do. ...	Heavy Tank, ten coupled	10	4 8½	Coke	15·0	78	158	2·06	·69	14	6	1245	1328
A. Borsig, Berlin...........	Minden & Coln.	Mixed, four coupled	6	4 8½	...	11·6	65	156	1·94	...	18	9	960	1025
R. Hartmann, Chemnitz	....	Do. do.	6	4 8½	...	11·5	70	148	...	...	...		790	860

Locomotives in International Exhibition 1862.

Name of Maker.	Cylinders.			Diameter of Driving Wheels.	Diameter of Blast Orifice.	Steam Pressure in boiler.	Height of centre of boiler above rails.	Length of Wheel base.	Weight of Engine Empty.				Weight of Engine in Working Order.			
	Inside or Outside.	Diam.	Stroke.						Leading wheels.	Middle wheels.	Trailing wheels.	Total Weight.	Leading wheels.	Middle wheels.	Trailing wheels.	Total Weight.
		Ins.	Ins.	Ft. Ins.	Ins.	Lbs.	Ft. Ins.	Ft. Ins.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
L. & North Western Ry. Co.	In.	18	24	7 6	5·25	150	7 5	18 0	10·60	13·30	7·30	31·20	11·90	14·30	8·50	34·70
Do. do. ...	Out.	16	24	7 7½	4·50	120	6 6	15 5	9·60	8·00	6·40	24·00	9·40	11·50	6·10	27·00
Beyer Peacock & Co.	In.	16	22	7 0	4·50	120	7 1	15 4	8·50	10·70	6·30	25·50	9·20	11·60	7·50	28·30
Neilson & Co.	Out.	17¼	24	8 2	5·50	120	6 6	15 8	...	...	...	27·25	9·25	14·55	6·85	30·65
Sharp Stewart & Co.	In.	17	24	5 0	4·87	120	6 4	15 6	9·35	10·70	8·55	28·60	10·65	11·55	9·85	32·05
W. Fairbairn & Sons	In.	16	24	5 2	4·25	140	6 5	16 6	11·80	8·85	7·80	28·45	12·30	11·25	8·70	32·25
Sir W. G. Armstrong & Co.	Out.	16	22	5 7	4·50	120	6 8	15 4	10·63	11·06	7·96	29·65	11·47	12·55	8·67	32·69
R. Stephenson & Co.	Out.	17	24	6 1	4·50	110	5 10	15 1	10·00	10·05	9·40	29·45	11·10	10·70	10·05	31·85
G. England & Co.	Out.	11	17	4 0	3·50	120	5 3	10 0	...	...	...	15·00	...	...	...	17·00
Manning Wardle & Co. ...	Out.	9	14	2 9	2·62	120	4 0	4 9	...	—	...	8·75	...	—	...	10·25
Neath Abbey Iron Co. ...	Out.	8	16	2 4	2·00	80	1 11	4 0	2·82	—	2·98	5·80	3·27	—	3·58	6·85
Orleans Railway Co.	Out.	15·75	25·50	6 7¾	...	...	...	14 1	9·50	11·45	4·50	25·45	10·65	12·50	5·35	28·50
Cail & Co., Paris	In.	18·00	26·00	5 0	...	120	...	11 4	...	...	...	...	...	...	...	...
Northern of France Ry. Co.	Out.	18·90	18·90	3 6	...	118	7 8	12 6	...	...	...	31·23	10 44	10·64 10·54	11·04	42·66
Société de Couillet	In.	17·60	23·50	4 9	variable	...	6 5	13 1	...	...	...	...	11·00	11·45	11·00	33·45
Austrian State Ry. Co. ...	Out.	10·87	24·87	6 9	variable	...	...	11 5	...	...	...	...	9·84	9·54	12·30	31·68
Do. do. ...	Out.	18·12	24·87	3 3½	variable	...	...	19 3	...	...	...	...	9·15	8·27 9·69	6·79 12·11	46·01
A. Borsig, Berlin............	Out.	17·00	22·00	4 6	...	100	...	11 0	...	...	...	...	8·00	12·00	12·00	32·00
R. Hartmann, Chemnitz	Out.	15·00	22·00	4 6	...	...	...	11 9	...	...	...	...	7·00	10·50	10·50	28·00

the water with the exhaust steam: but the injector may be used with surface heaters, in which the water whilst on its way to the boiler may be heated after it has passed through the injector, by contact with steam-heated surfaces.

The **Chairman** remarked that the locomotive engines formed an important and interesting feature of the Exhibition, and the paper just read contained a valuable summary of the principal varieties of construction presented by them. The improvements effected since 1851 were perhaps not very striking to a casual observer, except in the important change from coke to coal, in which respect certainly a very great improvement had been made during the past eleven years, causing a large saving in consumption of fuel; and other valuable improvements in working had also been carried out. He asked what were the comparative results of different engines in economy of fuel.

Mr. **Clark** replied that the question of the comparative value of the firebox and of the tubes as heating surface, to which he had referred, was one requiring particular attention: and he thought the two London and North Western engines exhibited furnished valuable information upon this subject. The performance of the inside cylinder engine with 242 square feet of heating surface in the firebox was not so good in work done per lb. of coal as that of the outside cylinder engine with only one third that extent of heating surface in the firebox but rather more in the tubes.

The **Chairman** enquired how many of the water troughs there were now in use, for enabling the engines to take up a supply of water into the tender whilst running, as described in the paper.

Mr. F. W. **Webb** replied that there were now three pairs of troughs on the London and North Western Railway: one near Conway, another at Parkside on the Liverpool and Manchester line, and the third near Wolverton. They were all working with complete success, and no difficulty was ever experienced in taking up the required supply of water at any speed above 15 miles an hour. The trough at Parkside was used for the heavy through goods trains, which were now enabled to run through without stopping, avoiding the serious obstruction of the line previously caused by their having to stop for water; and the troughs at Conway and Wolverton were used for the express and mail trains. An engine had on one occasion run through with a train from Holyhead to Stafford without stopping, a distance of 130½ miles, by means of picking up water from the trough at Conway; that was the longest run that had ever been made yet without stopping.

The CHAIRMAN enquired what were the steepest inclines worked by locomotive engines, and how much weight the engine could take up in such cases.

Mr. CLARK said the steepest gradient worked by locomotives that he had heard of was 1 in 17 on the Mountain Top Incline of the Virginia Central Railway, which was stated to have been worked safely by locomotive engines for several years with no accident. On some of the continental railways also there were inclines of 1 in 20 worked by locomotives, and when properly managed the engine could be made to take up them nearly as much as its own weight of train, but then every artificial help was required to increase the adhesion. On the American lines he understood chalk was sometimes used to increase the bite of the wheels, or else ordinary sandboxes; and in some places the curves were so sharp that oil was employed to lubricate the flanges of the leading wheels. On the Giovi Incline of 1 in 29 on the Sardinian Railway two four-wheeled tank engines were employed, coupled together tail to tail with the enginedriver between them; but this arrangement involved two complete engines with separate boilers and machinery, besides the extra trouble of working two boilers instead of one: and he therefore thought Messrs. Meyer's plan of a single large boiler mounted on a swivelling frame was superior in respect of simplicity and diminution of first cost, and a principal point in this engine was the swivelling connexion of the frame for carrying the long boiler.

Mr. W. **Bouch** enquired how the steam communications to the two pairs of cylinders were managed in that engine so as to allow of the frame swivelling: he thought any arrangement of flexible tubes for the purpose must be a source of much trouble in practice. No doubt a connexion between the engine and tender for driving the tender wheels was desirable for obtaining the benefit of the additional adhesion; but the difficulty in all such cases was the additional complication involved.

Mr. **Clark** said the communication from the boiler to the cylinders on a swivelling frame must certainly be a delicate point, and he thought the ball-and-socket coupling such as was used in ordinary tender feed-pipe connexions was decidedly superior to any plan of tubes with flexible india-rubber joints.

The **Chairman** enquired whether any of the locomotives exhibited had iron fireboxes or iron tubes, or whether they had all copper fireboxes and brass tubes, as in the ordinary English engines. He had heard much diversity of opinion as to the comparative value of brass and iron tubes, for though the difference in first cost was so great, the difference in the wear and tear and in disposing of the old materials when worn out was said to make the actual economy about the same in both cases.

Mr. **Clark** replied that there were no iron fireboxes or iron tubes in the locomotives exhibited; but the Prussian engine built by Borsig of Berlin had fireboxes made of homogeneous steel, and also tubes of the same material. The other foreign locomotives had all brass tubes, and he believed it was now almost the universal practice to use brass tubes, as these were found so much more durable in locomotives than iron.

Mr. J. **Fernie** remarked that on the English lines brass tubes were the only ones that were found to stand well, and he knew of no large line on which iron tubes were used. With regard to the various arrangements of large engines that had been described for working heavy inclines, he thought they would not apply to this country, as there were scarcely any English lines requiring anything beyond a large size six-wheel-coupled engine. They had on the Midland Railway the steepest incline worked by locomotives on a main line in this country, the Lickey Incline of 1 in 37, which was worked by a large six-wheel-coupled tank engine, the wheels being 4 feet diameter, and the cylinders 16½ inches diameter with 2 feet stroke; the weight on each pair of wheels for driving adhesion was about 12 tons in this case. In reference to the dimension of the water spaces between the boiler tubes in the locomotives exhibited, and the disposition of the frames and the weights upon the several pairs of wheels, there might be room for considerable difference of opinion from the views expressed in the paper; but he considered they were greatly indebted for the valuable information which the paper afforded on so extensive and important a subject.

The CHAIRMAN proposed a vote of thanks to Mr. Clark for his paper, which was passed.

The Meeting then terminated.

PROCEEDINGS.

4 and 5 August, 1863.

The Annual Provincial Meeting of the Members was held in the Concert Room, St. George's Hall, Liverpool, on Tuesday, 4th August, 1863; William Clay, Esq., Chairman of the Local Committee, in the Chair.

The Minutes of the last General Meeting were read and confirmed.

The Chairman announced that the Ballot Lists had been opened by the Committee appointed for the purpose, and the following New Members were duly elected:—

MEMBERS.

John Armstrong,	Sunderland.
Arthur Butler,	Surdah, Bengal.
Andrew Craig,	Birkenhead.
Isaac Hartas,	Rosedale.
Roger Hind,	Warrington.
Walter Stuart Hutton,	Leeds.
Edward A. Jeffreys,	Low Moor.
Bryan Johnson,	Chester.
Evan Leigh,	Manchester.
Edward R. Lloyd,	Birmingham.
William Muir,	Manchester.
Edwin Richards,	Pontypool.
Edward Tomlinson,	Manchester.
William Townsend,	Coventry.
Peter Wright,	Dudley.

HONORARY MEMBERS.

William Brookbank, ...	Manchester.
William Butler, ...	Cadiz, Spain.
John Fisher, ...	Dudley.
John Woolley, ...	Ripley.

The following paper was then read :—

ON THE CONSTRUCTION OF IRON SHIPS.

By Mr. JOHN VERNON, of Liverpool.

The extended and increasing use of Iron Ships at the present day, after the lapse of about thirty years since they were first fairly introduced, renders their construction a subject of importance in a commercial point of view, and of deep interest to all concerned in the development of science as connected with iron structures generally. The application of iron in place of wood to the structure of ships has necessitated a more careful use of the material employed, and a more correct and perfect application of the mechanical principles that are involved in the construction. It is not intended in the present paper to describe novelties of construction in iron ships, so much as to investigate the present systems that are most approved and practised; and when the great difference is considered between a proper and an improper use of the material employed, and the important results that depend upon it, the advantages of such an investigation become evident.

The rapid rate of increase in the application of iron for the construction of ships is strikingly illustrated by the following facts. In the year 1851 there were built and registered in the United Kingdom 55 iron sailing ships and steamers of a gross tonnage of 15,826 tons; while in the year 1862 the number had increased to 219 vessels and 106,497 tons. In the same years the number of vessels built of timber was as follows: in 1851 there were 617 vessels of a gross tonnage of 133,811 tons, while in 1862 the number of vessels was 740 and the gross tonnage 115,955 tons. It is thus seen that during this period of eleven years there was an increase of 570 per cent. in the tonnage of iron vessels, but a decrease of 13 per cent. in the tonnage of wood vessels; which is the more remarkable from the fact that less than twenty years ago it was considered by many persons of great experience to be a matter of doubt whether iron ships could be adopted at all for general service with any advantage. This doubt however was not shared in by many thoughtful mechanical men, who were strongly impressed with the advantages to be obtained from the introduction of iron; and the correctness of their views is now thoroughly established by the practical results that have been obtained on such an extensive scale.

The first consideration in the order of the subject will be the main points of superiority of iron ships over those built of wood. These consist in the superior strength, greater durability and less cost of iron ships, together with their larger carrying capability, greater facility of construction, and the more certain supply of the material.

The greater strength of iron ships is shown in daily practice in numerous ways; and it is also shown by the fact that in many modern wood ships it has been found desirable to introduce the use of iron for bulkheads, beams and stringers, and even for the framework itself of the whole structure. But this arrangement it is considered falls very far short in point of strength of a vessel built entirely of iron; and the only ground upon which such a mixed kind of structure can be advocated is the freedom from fouling possessed by wood vessels when they are coppered, which is an advantage existing in the mixed structure on account of the shell portion being of wood.

The greater comparative durability of iron for the construction of ships arises mainly from its freedom from the decay to which wood is always liable in consequence of its being unavoidably subject to constant and extreme variations of temperature and moisture. Another important source of this greater durability is to be found in the firm and substantial union of the several parts of an iron ship by means of rivetting, which effectually prevents that "working" under heavy strains to which all wood ships are more or less liable.

In reference to the question of cost, the comparison in order to be fairly drawn has to be made between the highest class of wood ships as built in this country, with frames of British oak and the bottom coppered, and the highest class of iron ships. The difference in favour of the latter is in that case about £3 per ton measurement or about 14 per cent.

The larger carrying capability of the iron ship arises first from the reduced weight of the structure, and secondly from the increased internal capacity with the same external dimensions and model as the wood ship. This is shown by the following figures of comparison of a 1200 ton ship of the two constructions. First as to weight. The wood ship with rigging and all outfit weighs say 18 cwts. per ton measure, equal to 1080 tons for the whole ship. The iron ship completed in a similar way weighs only say 15 cwts. per ton measure, which would be equal to 900 tons for the whole ship. Hence the 1200 ton iron ship will carry at the same draft 180 tons additional dead weight of cargo; and this will be equal to 11 per cent. addition upon the whole weight of 1600 tons which is actually carried by a nominal 1200 ton wood ship: or if no greater weight be carried, the iron vessel will float at 13 inches less draft of water. Secondly as to capacity. The wood ship has an internal capacity of 93,343 cubic feet, or at 100 feet per ton 933 tons. The iron ship, because of the reduced thickness of the sides and bottom of the hull, has a capacity of 1108 tons. Hence in regard to capacity the gain of the iron ship is 175 tons or about 19 per cent. over the wood ship; and there will consequently be space enough to contain the increased weight of 11 per cent. which the iron ship is capable of carrying by reason of its lighter hull.

As to facility of construction it may be remarked that, instead of a long period being required for preparation and seasoning of the material, as is necessary for a wood ship, the material for the iron ship can on the other hand be used immediately after it is manufactured. Also wood can only be had just as it has grown by nature, and it has to be converted to the purposes required, mostly by hand labour; but the iron can at once be obtained of the precise sizes and forms required, and the use of machinery can be very largely adopted in working it up in the structure of the ship, whereby a great amount of economy can be effected, both in the time occupied and in the cost of labour.

The next point to be considered is the actual strength of an iron ship and its capability of bearing strain; and whether the distribution of material is judicious and efficient, considering the strains to which it is subjected. For this purpose the case will be taken of a ship of 1200 tons, as shown in side elevation in Figs. 1 and 2, Plate 32, the dimensions of which are 205 feet length, 34½ feet beam, and 23 feet depth of hold; and the ship is supposed to be built to class A 1 at Lloyds' for 12 years or for 20 years with the Liverpool Underwriters' Association, which is considered the best construction at the present day. The transverse section of such a ship is shown to a larger scale in Fig. 3, Plate 33, the section of the iron being shown black; and the sectional area of iron is as follows:—

	Fig. 3.	Sq. Ins.
Stringer plates, tie plates, and angle irons on main deck	A	77
Do. do. do. on lower deck	B	55
Sheer strakes	C	61
Sides down to top of bilge	D	298
Turn of bilges and flat of bottom	E	379
Garboard strakes	F	59
Middle keelson	G	42
Sister keelsons	H	43
Bilge keelsons	I	20
Lower hold stringers	K	41
Keel piece	L	26
Total . . .		1101

In the above sectional area the deck planks, amounting to 1770 square inches, have been excluded from the calculation, because although aiding considerably when in compression they are of very little value for tension; and both cases have to be taken into account.

Taking first the extreme case of strain upon the vessel when supported only at the ends, and allowing 10 feet length at each end for the support, the ship will be as shown in the diagram, Fig. 1, Plate 32, with a length of 185 feet between the supports: in this case the bottom of the vessel is in tension and the top in compression. The displacement of such a vessel at her loaded draft of 20 feet is 2703 tons, and this weight is made up as follows:—

		Tons.
Iron in hull for 1166 tons measurement, at 10½ cwts. per ton	612	758
Woodwork do. do. at 2½ cwts. per ton	146	
Rigging and outfit	108	1945
Water and general stores	85	
Weight of cargo	1802	
Total . . .		2703

The cargo and other load carried is thus seen to amount to 1945 tons, which load is unequally distributed over the length of the ship in consequence of the larger capacity in the midships as compared with that at the two ends: and the proportionate distribution as measured from actual sections of an existing ship is shown approximately by the figures marked upon the side elevation, Fig. 1. The length unsupported being divided into six equal portions, the respective cargo capacities or loads of these are in the proportions of 11, 20, 23, 23, 22, 14 respectively, proceeding from the stern to the bows. The result obtained by taking the mean effect of these several loads at the centre of the vessel is that the strain produced at the centre by the distributed load amounts in this case to 74 per cent. of the total load, instead of 50 per cent. or one half the load as would have been the case if the distribution of the load had been uniform throughout the entire length. Hence the total distributed load carried being 1945 tons, as ascertained above, the equivalent centre load will be in this case 74 per cent. of that amount or 1440 tons; and the additional weight of the vessel itself, 758 tons, may be considered as equivalent to a load of one half the amount or 379 tons at the centre; making together a total load at the centre of 1819 tons, one half of which or 909 tons is acting at each end by tension on the lower part of the vessel, with a leverage of 92½ feet, or half the length of the unsupported portion of the vessel.

As the form in which the material is placed in the sectional area of the ship is necessarily determined by the carrying and floating requirements of the ship, and is consequently not free to be arranged in the manner that would simply give the greatest strength as a girder, this case does not admit of satisfactory comparison with a wrought iron box-girder for calculation of the transverse strength. It may be convenient consequently to consider the strains on the whole sectional area as if acting upon a solid girder composed of the material that exists at each point in the depth of the vessel, concentrated into a solid girder of the same sectional area and depth. The diagram, Fig. 4, Plate 33, shows the total sectional area of the vessel drawn to double the scale of Fig. 3 in area, or 1-5000th of the actual area of section. The metal is here condensed into the form of a flanged girder for comparison of the areas of resistance in the several portions, in order to deduce an approximate neutral axis for the whole section; and the positions of the several portions of the girder are made to correspond with the exact positions in the general section of the vessel itself, Fig. 3. The sectional areas of iron at the main deck, lower deck, and bottom are 113, 55, and 493 square inches respectively. The top flange of 113 square inches area is made up of the main deck plates and angle irons A of 77 square inches, and 36 square inches of the sheer strakes C from the top M downwards: the bottom flange is taken to include the entire section of iron in the bottom E E of the vessel, from the keel L up to the points O O at turn of bilge on either side, together with the five keelsons G, H H, and I I. The intermediate areas of the sides are 120 square inches between the upper and lower decks, from the sheer strakes C down to the lower deck N; and 320 square inches from the lower deck N down to the point O, at which the bottom is considered to begin: the latter area being divided into two portions of 158 and 162 square inches respectively above and below the neutral axis P P. Then these several areas multiplied into their respective vertical distances or leverages give the upper dotted line P P as the approximate neutral axis, about which the moments of the areas above and below are equal; taking the total compression resistance of the upper portion as 5-6ths of the tensile resistance of the lower portion, since the ultimate strength per square inch of wrought iron to resist compression is 5-6ths of its strength for tension.

In this case the decks being in compression and the 4 and 3 inch planks of which they are composed being fixed tight and solid together, the timber will contribute materially to the strength of the ship. The resistance of the pine wood to compression may be taken at 3 tons per square inch; and the compression strength of wrought iron being 17 tons per square inch or 5-6ths of its tensile strength of 20 tons, the strength of the wood is about 1-6th that of wrought iron: the value of the timber may therefore be safely taken at 1-8th of the strength of wrought iron per square inch. Hence the sectional area of the main deck planking being 960 square inches, 1-8th of this or 120 square inches has been added in the above calculation to the area of the top flange of the girder in Fig. 4, Plate 33, as shown by the outer lines surrounding the shaded portion, making the total area of the top flange 233 square inches. For the lower deck of 810 square inches sectional area, 1-8th of this or 101 square inches has similarly been added, making a total area of 156 square inches.

The neutral axis P P thus found is situated 9 feet above the centre line of the bottom portion, Figs. 3 and 4, Plate 33; and the strain tending to produce fracture at the centre of the vessel will therefore be 909 tons × 92½ ÷ 9 = 9343 tons. Then assuming this strain to be resisted by all the portions in tension in proportion to their respective distances from the neutral axis P, the effective area resisting by tension will be 493 square inches for the bottom portion, and 1-3rd of 162 or 54 square inches for the lower sides; since the centre of gravity of the lower sides, from the neutral axis P down to the point O in Fig. 3, is only a little more than one third of the way down from the neutral axis P to the centre line of the bottom portion, as seen in Fig. 3. Hence the total effective area resisting tension is 547 square inches, on which the above load of 9343 tons gives a strain of 17 tons per square inch upon the iron.

This calculation is on the extreme supposition of the vessel being entirely out of the water and supported only at the two extremities; but practically the vessel when carrying her cargo is supported from end to end by the water, excepting to the extent that this support may be partially withdrawn by the waves and other causes producing an inequality of immersion. It has to be observed that, although the weight of the whole vessel is balanced by its displacement, the extreme ends are very much heavier than their own displacements, and consequently a larger weight is left unsupported at the ends; and the effect of this imperfect support of the ends of the vessel while afloat, inasmuch as it throws a strain of compression on the bottom, will to that extent reduce the strain of tension to which the bottom of the vessel is exposed in the case now under consideration, when she is supported at the ends only.

Now considering the opposite case of the vessel being supported only at the centre, as shown in Fig. 2, Plate 32, the strains on the vessel will then be reversed: the top will be in tension and the bottom in compression. In this case the effect of the unequal distribution of the load, taken from the same data as before, will be to produce a strain corresponding to a load at the ends of the vessel amounting to only 44 per cent. of the total load, instead of 50 per cent. or one half as would have been the case if the load had been uniformly distributed throughout the entire length. The total distributed load carried being 1945 tons as before, the equivalent load at the ends will in this case be 44 per cent. of that amount, or 856 tons acting at the two ends; and the additional weight of the vessel itself, 758 tons, being taken as before to be equivalent to one half that amount or 379 tons at the two ends, these make together a total load at the two ends of 1235 tons, one half of which or 617 tons is acting at each end by tension on the upper part of the vessel, with a leverage of half the unsupported length of the vessel or 92½ feet as before.

The neutral axis in this case, found in the same manner as before, but omitting from the calculation the sectional area of the decks which are now in tension, is shown by the lower dotted line Q Q, Figs. 3 and 4, Plate 33; it is situated at a depth of 16¼ feet below the centre of the upper portion, or 21 inches below the previous neutral axis P, thus dividing afresh the 320 square inches area of the lower sides from N to O, Fig. 3, into two portions of 181 and 139 square inches respectively above and below the neutral axis Q, as seen in Fig. 4. The strain tending to produce fracture at the centre of the vessel will therefore be 617 tons × 92½ ÷ 16¼ = 3512 tons. Then the effective area resisting by tension, found in the same manner as before, will be 113 square inches for the main deck portion, together with ¾ of 120 or 90 square inches for the top sides between the decks, ½ of 55 or 27 square inches for the lower deck portion, and ¼ of 181 or 45 square inches for the sides below the lower deck; making a total effective area of 275 square inches resisting by tension.

Hence the strain produced by the above load of 3512 tons will be 13 tons per square inch upon the iron.

It may be observed that, although this is an extreme case, it is by no means imaginary as regards the strain which a vessel has to bear continually when floating in the water. For the effect of the imperfect support of the ends of the vessel while afloat, which was previously referred to, is to cause a strain on the transverse area of the midship section similar in action to that caused by the vessel being supported in the middle alone, entirely out of the water, and differing only in degree.

As is well known there are many new plans and improvements in the construction of iron vessels that are partly adopted or in contemplation to be used, which might have been referred to in this paper; but the subject of the paper has been confined to an investigation of the strength and efficiency of iron vessels as generally built of the highest class at the present time. In considering however the strength of any new kinds of structures, the same principles are applicable that have been employed in the case now dealt with.

In order to ascertain the comparative strength of iron and wood ships under the two extreme conditions of strain, the same calculation will now be applied to a wood ship of the first class, such as has been previously referred to, and of the same size, 1200 tons; of which a transverse midship section is shown in Fig. 5, Plate 34, drawn to the same scale as the section of the iron ship in Fig. 3. In Fig. 6 is shown as before, condensed into the form of a solid girder, the area of section of the wood ship, drawn to double the scale in area of Fig. 5, or 1-5000th of the actual area of section. The bottom flange of the girder, Fig. 6, is taken to include all the section of material in the bottom of the vessel, from the keel up to the points R R on either side in Fig. 5. The actual areas of each portion of the section are as marked upon the drawing, Fig. 6; namely 1011 and 1074 square inches in the main deck and lower deck portions respectively, exclusive of the decks themselves; 764 square inches in the sides between the upper and lower decks; 1736 square inches in the lower sides from the lower deck down to the point R where the bottom is considered to begin; and 5216 square inches in the bottom. In these areas the "ceiling" or lining of the hold, being constructed of 4 inch planking secured to the frames of the ship, has been included as acting efficiently both in compression and tension.

When the vessel is supported only at the ends, having the bottom in tension, the main and lower decks, of 944 and 920 square inches area respectively, have to be included in the compression resistance, as in the iron ship; thus the areas of the main and lower deck portions are here increased to 1955 and 1994 square inches respectively, as shown by the outer lines surrounding the shaded portion in Fig. 6, Plate 34. The neutral axis in this case is shown by the lower dotted line P P: it is obtained in the same manner as before in the iron ship, by multiplying the several portions of the section, Fig. 6, into their respective leverages or vertical distances from the line P P, so as to make the moments equal above and below that line; the only difference for the wood ship is that here the ultimate resistance of the timber to compression is taken as 3-4ths of its resistance to tension. This gives the neutral axis P at 6¾ feet above the centre line of the bottom flange of the girder in Fig. 6, dividing the lower sides into two portions of 1041 and 695 square inches respectively above and below the neutral axis.

The weight of the 1200 ton wood vessel without cargo is 18 cwts. per ton measure, or 1080 tons total, as previously stated. Deducting 143 tons for the weight of the rigging, outfit, water, and stores, the same as in the iron vessel, the weight of the hull is 937 tons; half of which, or 468 tons, is therefore taken as the equivalent load at the centre. The internal capacity of the wood ship having been already stated to be only 933 tons as compared with 1108 tons capacity of the iron ship, the total distributed load of 1945 tons carried by the iron ship will be reduced in the same proportion, amounting to 1638 tons: and the equivalent centre load being 74 per cent. of the distributed load, as before, amounts in this case to 1212 tons. The total centre load is therefore 1680 tons, or 840 tons at each end of the ship, with a leverage of half the unsupported length of the vessel or 92½ feet.

Hence the strain tending to produce fracture at the centre of the vessel will be 840 tons × 92½ ÷ 6¾ = 11511 tons tension upon the portions of the section below the neutral axis, Fig. 6, Plate 34. The effective area resisting this strain is 5216 square inches for the bottom portion, and 1-4th of 695 or 174 square inches for the sides below the neutral axis; since the centre of gravity of the sides, from the neutral axis P down to the point R in Fig. 5, is only 1-4th of the way down from the neutral axis P to the centre line of the bottom portion, as seen in Fig. 5. The total effective area resisting tension is therefore 5390 square inches, on which the above load of 11511 tons produces a strain of 2⅛ tons per square inch.

In the opposite case of the vessel supported only at the centre, the top is in tension, and the decks are therefore not included in the resistance. The neutral axis, found as before, is shown by the upper dotted line Q Q, Plate 34, which is situated 14 feet below the centre line of the upper portion, Fig. 6, or 6 inches above the previous neutral axis P; thus dividing afresh the 1736 square inches area of the lower sides into two portions of 935 and 801 square inches respectively above and below the neutral axis Q, as seen in Fig. 6. The weight of the hull, 937 tons as before, is equivalent to half that amount or 468 tons at the two ends; while the distributed load of 1638 tons in the wood ship is equivalent to 44 per cent. of that amount or 721 tons at the two ends. Hence the total load at the two ends is 1189 tons, one half of which or 594 tons is acting at each end by tension on the upper part of the vessel, at the leverage of 92½ feet as before.

The strain tending to produce fracture at the centre of the vessel is therefore 594 tons × 92½ ÷ 14 = 3925 tons tension upon the portions of the section above the neutral axis Q, Fig. 6. The effective area to resist this strain, found as before, is 1011 square inches for the main deck portion, together with ¾ of 764 or 573 square inches for the top sides between the decks, ⅜ of 1074 or 403 square inches for the lower deck portion, and ⅐ of 935 or 134 square inches for the sides below the lower deck. This gives a total effective area of 2121 square inches resisting by tension, upon which the above load of 3925 tons produces a strain of 1⅞ tons per square inch.

Thus if the average tensile strength of all the wood employed in the longitudinal timbers and decks of the ship, namely teak, greenheart, elm, and pine, be taken at 6 tons per square inch in the solid material, and the effective strength be taken at one third of that amount or 2 tons per square inch, in order to allow for the joints, the result obtained is that the greatest possible strain to which it could be exposed, namely in the case of the vessel being supported at the ends only, is 2⅛ tons per square inch, as above ascertained, or 6 per cent. in excess of the tensile strength of the material: while in the other case of the vessel being supported only at the centre, the strain of 1⅞ ton per square inch is 6 per cent. less than the strength of the material. In the iron ship, if the tensile strength of the material be taken at 20 tons per square inch, and the effective strength at three fourths of that amount or 15 tons per square inch, the greatest strain to which it can be exposed, namely 17 tons per square inch in the case of the vessel being supported at the ends, exceeds the strength of the material by 13 per cent.; and in the opposite case of the vessel supported at the centre, the strain of 13 tons per square inch is 13 per cent. less than the strength of the material.

The general result therefore as regards the comparative strength of the iron and wood ships appears to be that in the position causing the greatest possible strain in each case, namely when the ship is supported at the ends only, the strength of the material is deficient for resisting the strain by about one eighth in the iron ship and one sixteenth in the wood ship: and in the other position of strain, namely when the ship is supported in the middle, there is an excess of strength in the material of about one eighth in the iron ship and one sixteenth in the wood ship. A very important consideration however affecting this comparison of the strength of iron and wood vessels is that the wood vessel selected for the comparison is one of the very first class, as constructed by the first builders in this country; whereas nearly all foreign vessels and most others in this country besides the special few referred to are very much inferior to the one on which the calculations have been founded.

The iron used in the framework of iron vessels is applied in various forms of section of single or compound structure. Those which are principally employed are shown in the sections, Figs. 7 to 30, Plates 35 to 38, all drawn to a scale of one tenth full size.

For Keels, the section shown in Fig. 7, Plate 35, is that in most common use, as seen at L in Fig. 3, Plate 33. It consists of a plain parallel bar S, Fig. 7, about 8½ inches deep by 3 inches thick for a 1200 ton ship. This is forged in lengths of about 20 feet, and then pieced up by welds into two or three lengths for the entire ship, having scarfed joints of a length of eight times the thickness of the keel, which gives room for as many rivets as are required to correspond with the section of the keel. Fig. 9 is a deep keel of plate iron, made by putting two or more plates side by side, breaking joints in every way. The plates are 1 or 1¼ inch thick and from 3 to 4 feet deep: they are adopted when a forging of the required size would be too large and heavy, say for vessels of 2000 tons and upwards; and where the scarfing would also be comparatively imperfect. This arrangement is specially adopted in order to be made to serve as a keelson as well. The floor angle irons T T have to be turned up at the foot so as to be rivetted through and through the keel plates; and the floor plates U U are thus made in two pieces, one on each side of the keel. The keelson angle irons V V are put on the top of the floor plates and rivetted through and through the top edge of the keel plates. Fig. 10 is the "dished" keel, specially suited to flat bottomed vessels, in which it forms an excellent trough for drawing off the last drop of bilge water. It is made of plates about 1 inch thick bent or rolled to the required section. The trough is made of a shape to suit the circumstances, from 6 to 8 inches wide and 2 to 4 inches deep. Fig. 8 shows an arrangement with a flat plate as a substitute for a keel for flat bottomed vessels, where the draft is limited to the smallest possible amount; and a watercourse is obtained by an opening W in the bottom edge of the floor plate U and by cranking up the angle iron to correspond.

For Keelsons, the section shown in Fig. 11, Plate 36, is that required by Lloyds' rules, and is 2-3rds the depth of the floor plates. Fig. 12 shows the box keelson, seen at G in Fig. 3, Plate 33, which

The application of iron for building vessels is peculiarly advantageous in the special class of Screw Colliers that have recently come into use, with hollow bottoms for carrying water ballast. The traffic in which these vessels are engaged does not usually provide any return freight, and it is obvious a great commercial advantage is obtained by this method of water ballasting for the return voyage, which is accomplished without any delay and with but little cost. Figs. 35 and 36, Plate 39, show transverse and longitudinal sections of an iron screw collier with water ballast, in which it will be seen that a water chamber is formed by the hollow space of the double bottom G G, and a chamber is also obtained in each of the extreme fore and aft compartments H and K, Fig. 36. When the vessel is required to be ballasted, the large sea cocks are opened and water is admitted into the hollow bottom G and the aft compartment K, so as to fill these two portions; and then the water is also admitted into the fore compartment H, to such an extent as may be found necessary for adjusting the draft of water and the due immersion of the screw. When the vessel has arrived in port, the steam pumps are set in action for pumping out the ballast water; or in a dry harbour at low water the large sea cocks are opened, and then the water is easily and quickly got rid of within the short time of the cargo being taken on board: and the vessel is thus got ready for sea again without having experienced any delay on account of discharging ballast. Figs. 35 and 36, Plate 39, represent the iron screw steamer "Annie Vernon," which is of 518 tons gross register, and 70 horse power. The weight of water ballast contained in the hollow bottom chamber G is 120 tons, in the aft compartment K 20 tons, and in the fore compartment H 30 tons, making a total of 170 tons of water ballast; and the cargo of coal or iron ore which the vessel carries is about 700 tons. The mean draft when in ballast is 8 feet, and when fully loaded with cargo 13 feet, as shown in the transverse section, Fig. 35.

There is perhaps no branch of iron shipbuilding in which more special advantages are obtained from the use of iron than in the construction of Flat Bottomed Boats for river navigation. The extremely small draft of water thereby obtained may be said to be utterly impossible except by the use of iron as the material of construction. An illustration of what is not an unusual specimen of vessels of this class is shown in Figs. 37, 38, and 39, Plate 40, which represent an iron paddle steamer, 226 feet long, 30 feet beam, and 7 feet depth of hold, fitted with engines of 170 horse power. This steamer draws only about 2 feet of water when light, and can be loaded with coal and cargo to a depth of 4 feet; it maintains a speed of 14 statute miles an hour when steaming alone, and 11 miles an hour with one barge in tow, 200 feet long and 30 feet wide with 370 tons of cargo on board, having a draft of 4 feet. In this construction of vessel two longitudinal iron girders II are introduced, rising considerably above the level of the deck, in addition to the sides of the vessel being raised as girders to the height of the paddleboxes, as shown at JJ, Fig. 37. The girders II are required in order to obtain the necessary longitudinal strength as a girder for carrying the weight of the engines and coal, the hull of the vessel being totally insufficient for this on account of its necessary shallowness and lightness. This vessel is made without a keel, as seen in Fig. 37; and with a spoon bow, as shown in Fig. 38, which is found to be a very advantageous form for facilitating getting the vessel off the sand banks that are so frequently met with in such rivers as the Ganges and Indus where these vessels are worked, in which it is found impossible to avoid at times going aground on the sand banks.

A novel system has recently been tried on the Indus for conducting the navigation by means of Bourne's floating steam trains, one of which is shown in Fig. 40, Plate 41. It consists of a paddle steamer L at the head of the train, having a convex stern fitting into the concave bow of the barge M next adjoining; and this barge has a concave stern which receives the convex bow of the second barge N. Other following barges OO, all with convex bows, are fitted together in a similar manner to the second barge, making up a train of five barges with an entire length of 640 feet including the steamer. The connexions between the barges are formed by a pair of radial connecting rods with ball-and-socket joints, thus making an articulated train capable of bending into any tortuous line that the navigation of the river may require. This system has not at present answered so well as was expected: the current of the river, both when with the train and when against it, is found to prevent that due control in steering the train which is requisite for keeping it in the winding course desired. The special advantage supposed to be obtained is that of having only one midship section for all the train, instead of one midship section for the steamer and one for each of the five barges: but it will be observed that this advantage, even if assumed to be ever possessed, cannot be realised whenever the train is out of the straight line, since the resisting area will then be necessarily increased in proportion to the curvature of the train.

Fig. 41, Plate 42, shows the area of canvas requisite to drive a first-class merchant ship of 1200 tons burthen, the size of vessel shown in the previous drawings, Figs. 1 to 5, Plates 32 to 34. This is the proportion usually adopted in first class vessels, giving a total area of 23,313 square feet of canvas. The area of the immersed midship section when laden being 612 square feet, the proportion thus obtained is 38 square feet of canvas per square foot of midship section immersed. This proportion is found in general practice with good models of ships to obtain with a good breeze of wind a speed of 12 knots an hour.

A question of great importance and interest that has recently arisen in reference to iron ships is, what is the advantage to be obtained by the use of steel in place of iron in their construction. The best steel used for this purpose is guaranteed to bear a tensile strain of 40 tons per square inch, while the best iron will bear only about 20 tons per square inch or half the strain. This would show that half the weight of steel might be adopted as an equivalent for the iron; but in practice it is not considered advisable to reduce the proportion lower than two thirds the weight of iron. Taking the matter in a mechanical point of view, there can be no objection to the adoption of steel for the purpose so long as it comes up to the professed standard of quality: but considering it commercially, the comparison is as follows, if the price of iron be taken at the average rate of £10 per ton, and the steel at £26 per ton. The iron in the hull of a 1200 ton ship as before stated is 612 tons, which taken at £10 per ton costs £6120. Then two thirds that weight of steel or 408 tons at £26 per ton costs £10,608. This shows the weight of the vessel to be reduced 204 tons by the use of steel, and its carrying capability thereby increased to the same extent; but this is obtained at an increased cost of £4488 as respects the raw material, or at the rate of £22 per ton for the additional weight carried. On the other hand the whole cost of the iron ship of 1200 tons, taken at £20 per ton, is £24,000; and its actual carrying capability being 1800 tons, its cost is about £13 per ton for the weight carried. It thus appears that the additional 204 tons of cargo would be carried by steel at a cost of £9 per ton more than by the iron bottom; and with this serious additional drawback, that with the steel the increased capability for carrying weight is not accompanied by any corresponding increase in internal capacity, as would have been the case if the additional weight had been carried by proportionately increasing the size of the iron ship at the lower rate of cost.

The above comparison would of course be reduced by risking a smaller proportion of steel, as well as by any reduction in its price. But in order to bring the two ships to an equality as regards total cost, it would be requisite to reduce the weight of steel as low as half the weight of iron and to reduce the price to £20 per ton, when 306 tons of steel would cost £6120 or the same amount as the iron. In that case the vessel would be able to carry additional cargo equal to the increased difference of weight, namely 306 tons, without additional cost; although without any corresponding increase of capacity for containing this additional cargo.

The mode of rivetting adopted in large first-class vessels is principally what is termed "chain rivetting," both in the longitudinal and vertical joints: but in addition the principal stringer plates in the upper part of the vessel, and the sheer strakes in the midships, have further rows of rivets with increased lap of the joint plates, making the joints in these cases treble or quadruple rivetted. The relative merits of holes punched or drilled appear to be not so different and not so much in favour of the latter as might be expected: the punched holes are not so regular and so direct through the thickness of the plates as the drilled holes; but notwithstanding this it is found in practice that the punched holes are thoroughly well filled by the rivets, which adapt themselves exactly to all irregularities of the holes; the drilled holes though perfectly parallel throughout are not better filled by the rivets than the punched holes, as is seen in the two specimens now exhibited, showing sections of plates rivetted together, one with drilled holes and the other with punched holes. It must be admitted at the same time that the plates are subjected to a somewhat greater strain by being punched than by being drilled, though the damaging effect from such a cause cannot be said to be at all apparent in the usual execution of good work.

The joints for the plating have now become more perfect than formerly, by the use of the planing machine. The edges of the plates for the butt joints are now planed perfectly straight and smooth, and they are thus brought into accurate contact with each other, so as to form a perfectly true and close joint, which could not previously be attained by shearing and the too common practice of hammering up the edges of the plates. All necessity for undue caulking and the use of lining strips is now avoided, and the best strength of the material is imparted to the ship. The quality of iron employed for ship building should in all cases be equal to a tensile strength of at least 20 tons per square inch; and a direct and habitual system of testing should be constantly carried out.

An important point connected with the construction of iron ships is the kind of tools employed and their special adaptation to the purposes for which they are required. Great improvements are constantly being introduced to meet the varied requirements as they arise from time to time, in order to accomplish greater accuracy and perfection of work with increased economy and dispatch. The ordinary tools in general use, such as punching and shearing, drilling, and bending machines, need not be specially referred to here: but attention may be called to some improved machines that have been recently adopted with very considerable advantage. Amongst these may be named a punching and shearing machine, which is fitted with sliding tables and is self-acting, by the use of which three or more holes can be punched at one time, and each of the four edges of the plates perforated as required with perfect accuracy and truly square with one another; and the shearing also of the four edges of the plates can be made perfectly straight and true, and nearly as smooth as if planed, the smallest width, even down to 1-64th inch, being accurately pared off the edges of the plates. Another machine is a plate-planing machine, by which the edges of the plates may be planed perfectly true with only one or two cuts; thus enabling the workmen to make the most perfect joints with great economy of time and labour. Another machine is a horizontal punching machine, whereby long curved frames may be punched while held in a horizontal position, thus dispensing with the necessary tackle and high roofs necessary if they were to be punched by an ordinary machine, which would require them to be held in a vertical position. The small machine for straightening angle iron by means of pressure from a screw, which is done silently and with perfect effect, is a great improvement upon the old plan of always doing this by the blows of heavy sledge hammers. Another machine specially useful and productive of economy is the multiple drilling machine, whereby a number of holes, up to twelve or even more, can be drilled at one time in keels, stem and stern posts, &c., with more accuracy of spacing than could possibly be obtained with the ordinary machines which can drill only one hole at a time.

The very extensive use of iron vessels at the present time has now proved that the only objections which can be urged against them are the liability of the bottoms to become foul by the adhesion of animal and vegetable substances, and the derangement of the compasses by the local attraction of the iron in the hull. First as regards the fouling, it has to be observed that the difficulty only exists in the case of vessels engaged on very long voyages, or detained at foreign ports where the water and climate are such as to encourage the growth and accumulation of those substances. This difficulty it must be admitted does exist to some extent with iron ships, and occasionally results in a considerable detention and delay: usually however vessels that are well coated with any of the suitable compositions now so extensively in use, which are destructive to animal and vegetable life, are able to prosecute their voyages out and home in almost any part of the world, without ever becoming foul at all, or at least to any extent that is seriously detrimental. The discovery of still better compositions will probably lead almost to the annihilation of this difficulty; and even if they do not effect this, there is no doubt that the graving docks, both on land and floating, and the slips that are now being adopted on such a large scale at many important foreign ports will give as great facilities for docking and cleaning the vessels as are possessed in this country, and thus remove the difficulty entirely. Secondly as regards the derangement of the compasses in iron ships by the local attraction of the metal in the hull, this exists in all ships to a greater or less extent, and perhaps there are no two vessels that are exactly alike in this respect. The mode adopted for meeting this difficulty is to neutralise the attraction by fixing permanent magnets in suitable positions found by a series of trials in each particular ship, the effect of which is to make the compasses nearly correct: the precise amount of incorrectness that still remains is then depicted upon what is called a card of errors for every position of the compasses. This plan affords practically the same results for working the ship as if the action of the compasses themselves were perfectly correct.

An application of iron or steel in place of hemp is now in use in first-class vessels for the standing or fixed rigging, that is those portions that are not what is termed running rigging. The effect of this change in a 1200 ton ship is that by adopting iron wire rope in place of hemp a saving in weight is effected of 3 tons, and in cost a saving of £200; and with steel wire rope the saving in weight is 6½ tons over hemp, but without any further saving in cost over the iron wire rope. Greater durability is obtained by the use of wire rope, and damage by moisture is prevented by the wires being galvanised, as well as by covering the wire rope in some cases with a serving of hemp yarn.

The adoption of steel and iron in place of wood for the masts and yards, which is now becoming so extensive, is a subject that requires to be well considered in order to secure the real advantages to be attained by the change of material, and at the same time to avoid the risks and dangers that would arise from making the change in an injudicious manner. That a saving of weight is effected by this change is shown by the fact that in a 1200 ton vessel the three lower masts and the bowsprit if made of iron weigh 26 tons, and if made of steel 19 tons, while if made of wood they weigh 32 tons. A corresponding advantage as regards weight is obtained by the use of iron and steel for the topmasts and yards: the weight of the three lower yards if made of iron is 8 tons, and if made of steel 5 tons, while if made of wood their weight is 9 tons. It may therefore be taken as approximately correct that if iron were wholly adopted for the lower masts, topmasts, bowsprit, and principal yards of a 1200 ton ship, an entire saving of 7 tons would be effected, which saving would be increased to 17 tons if steel were used.

An important point to be noticed in reference to this saving of weight is that it is effected at a position situated at a great height above the centre of gravity of the vessel. Thus in the case of a vessel being light, as for instance during the interval of time between discharging one cargo and taking in another, the saving of 17 tons weight resulting from the use of steel for the masts and yards will take place at a point P, Fig. 34, Plate 38, which is 32 feet above the centre of gravity Q of the vessel in that condition. Hence the centre of the temporary ballast R being 11 feet below the centre of gravity Q, it may be concluded that the result obtained by the saving aloft will be that more than 30 tons of ballast may be dispensed with in the bottom of the hold.

An experiment of some practical interest to show the comparative strength of one of the best pitch pine yards and a cast steel yard of the same dimensions has been carried out at the writer's works, of which the following are the particulars. The yards selected were the actual topsail yards that had been made for a 1200 ton ship, of the same external dimensions, namely 58 feet long, 15 inches diameter at the centre, and 7½ inches diameter at the ends, as shown in Figs. 42 to 45, Plate 43. For the testing they were carefully bedded upon timber supports 18 inches long with 51 feet clear length between, and were loaded in the centre by actual weights of pig iron in a cradle suspended by chains from a wood saddle S, Figs. 42 and 44, 2 feet long, carefully fitted upon the top surface of the yard. In each case the first load included the weight of the cradle and chains.

The successive loads and corresponding deflections of the two yards were as follows :—

1863.	WOOD YARD.		STEEL YARD.	
	Load.	Deflection.	Load.	Deflection.
	Tons.	Inches.	Tons.	Inches.
23 July	1·29	3·50	1·85	2·25
	1·55	4·00	2·06	2·50
	1·81	4·50	2·35	2·87
	2·08	5·25	2·63	3·19
	2·37	6·00	2·89	3·50
	2·55	6·50	3·10	4·12
	2·83	7·25	3·25	4·50
	3·09	7·75	3·46	4·75
	3·35	8·50	3·60	broken
	3·63	8·87		
	3·91	9·37		
	4·16	9·87		
	4·41	10·25		
	4·65	11·37		
	4·86	11·75		
	5·11	13·00		
	5·38	13·62		
	5·77	16·00		
	6·06	16·50		
	6·41	17·00		
	6·57	17·25		
24 July	6·61	21·50		
	6·85	22·25		
	7·09	23·00		
	7·31	23·75		
	7·52	24·50		
	7·83	25·50		
25 July	7·98	41·00		
	8·04	broken		

The wood yard, of pitch pine, had the load removed on the nights of the 23rd and 24th July, to allow of packing up the ends higher from the ground; and was left unloaded during the whole of those nights. At the end of the second day's testing, at the deflection of 25½ inches under 7·83 tons load, the wood began to show signs of fracture on the upper side: but the yard did not finally give way until the load of 8·04 tons was reached. The extreme deflection just before breaking was 41 inches, as shown in Fig. 42, Plate 43, being nearly 1-16th of the length of the yard. The fracture was very perfect in character, the lower side showing the effects of the tensile strain by longitudinal rents extending for so great a length as 12 feet; and the upper side showing the effects of the compression by the material being crushed up into a lump projecting above the line of the upper side of the yard at each end of the saddle piece; whilst the centre portion for nearly half the diameter, occupying the position of the neutral axis, broke off short and square, as seen in Fig. 43.

The steel yard, tested on the 22nd July, broke first at the point T, Fig. 44, Plate 43, about 6 feet from one end or 2½ feet from the support; and then on falling it broke at the point U, 5 feet from the centre on the opposite side. The first fracture T went completely round, and showed on examination a flaw or rather an old crack for almost a fifth of the circumference. The second fracture U did not go quite round, but opened about ⅛ inch on the bottom side. The section of the yard, Fig. 45, was very little altered by the load, and the top showed very little sign of buckling.

The general result of this experiment is that the steel yard broke with a little more than 3½ tons load, and with 4¾ inches deflection; whilst the wood yard required 8 tons to break it, with a deflection of 41 inches. It is only fair to observe however that in the manufacture of this steel yard some of the plates intended to be used were considered of inferior quality, having proved brittle whilst the yard was being made: but these were replaced by good plates at the time, so far as they could be discovered.

The **Chairman** remarked that the construction of iron ships was a subject of such vital importance in a large seaport like Liverpool that he was sure the excellent paper just read would be highly appreciated by the meeting, and they would feel greatly indebted to the author for having prepared it.

Mr. P. D. **Bennett** asked for some further explanation about the mode adopted for calculating the strength of an iron vessel as a girder. He could understand that when it was supported at the two ends the large amount of metal in the keel and bottom of the hull formed the bottom flange of the girder, resisting the strain of tension to which the bottom of the vessel was then subjected; but there appeared to be so little metal at the decks of the ship to act as a top flange for resisting the corresponding compression that he did not see how a vessel could be treated as a girder in that way. And in the contrary case of the vessel being supported in the centre, it then became a double cantilever, with scarcely any top flange for resisting the tension, and an excessive bottom flange for compression. Moreover in calculating the strength of wrought iron box-girders it was usual not to include the sides in the calculation, but only the top and bottom members of the girder; and he enquired how the sides of the vessel were taken into the account in calculating the strength of a ship when it was treated as a girder, as in the present paper.

Mr. **Vernon** replied that he had not attempted to apply to the case of a ship any arbitrary formula such as was used for ordinary box girders; because, although such a formula could be safely employed for rectangular box girders, from their general correspondence in distribution of material, yet in a ship the special form in which the material had to be distributed to meet the carrying and floating requirements necessitated so wide a departure from what would be the most effective distribution of the material in a box girder, that to treat the vessel as a box girder could not afford any satisfactory results. In the ship accordingly the plan he had taken had been to collect together the sections of metal in the entire midship section of the vessel, grouping the whole into a few separate portions at the points where the greater mass of the material was situated; and the result was a section of solid girder of the form shown in the diagram, Fig. 4, Plate 33, having two upper flanges corresponding in position to the upper and lower decks, and one bottom flange corresponding to the keel and bottom of the vessel, the chief portion of the material being by the construction of the vessel mainly concentrated at those three parts. The sides of the ship however necessarily contained also a large portion of material, and when brought together in the same way they formed the middle vertical web in the girder; and then the ultimate breaking strength of the whole was calculated approximately by taking the area of each of the three flanges and also of the middle web, and taking the distance of the centres of gravity from the neutral axis, as the leverage at which the several areas acted to resist the strain; allowing for the difference in ultimate strength of the material under tension and under compression. By this means two positions of the neutral axis were arrived at, one when the ship was supported at the ends, and the other when it was supported in the middle; in the latter case the two upper flanges of the diagram girder, corresponding to the material in the upper and lower decks of the ship, were in tension, acting then like the bottom flange of an ordinary box girder. By this mode of procedure he had attempted to arrive at an approximate estimate of the ship's strength, endeavouring to give neither too much nor too little value to any portion of the material, but to take as nearly as was practicable the effective value of each portion corresponding to its actual position in the construction of the vessel: and the object being to institute a comparison between the strengths of iron and wood vessels of similar form and size, the calculation though not assumed to be absolutely correct would afford a relative result of very considerable correctness.

Mr. T. R. **Arnott** observed that the addition of a pair of longitudinal box girders or strong deck beams had been recommended by Mr. Fairbairn, for strengthening the upper portion of the section of iron ships to resist the strains of tension and compression; as there appeared a deficiency of material at that part in the present construction of iron ships, when considered as a girder subjected to vertical strain.

Mr. **Vernon** said the deficiency of material in iron ships was certainly in the upper deck, as pointed out, and that was therefore the place where any additional material ought to be put; and no doubt the addition of longitudinal box girders as had been suggested was highly desirable and would greatly increase the strength of the vessel. The paper that had been read had been confined to the actual practice at the present time in building iron and wood ships, for the purpose of enquiring into the safety and correctness of the present mode of construction; and the same principles of investigation would be applicable to any new distribution of material which might be adopted for obtaining greater strength in the ship.

Mr. H. W. **Harman** observed that the question of the relative value of punched holes and drilled holes in rivetted work, which had been referred to in the paper, was really a very important one at the present time when iron entered so largely into all sorts of structures. Although drilled holes were thought to be necessarily the best, yet he considered the old fashioned punched holes had some advantages, the principal of which was that the punching afforded a rough test to the workmen as to the quality of the iron punched, leaving minute cracks in the burrs punched out in the case of bad or inferior iron, which were of great value in disclosing the quality of the metal: whereas drilling afforded no such test, passing equally through bad or good material, without furnishing any such indication of the quality. He therefore thought punching furnished a valuable criterion, and was not likely to be superseded by drilling, except in particular classes of work where extreme accuracy of the holes might be necessary. Punching had also the advantage that the punch inevitably made the holes slightly taper, giving the effect of a countersink; so that if two plates were rivetted together with the smaller ends of the holes inwards, a rivet would remain secure in its place and hold the plates together even without its head: but in drilled holes if a rivet lost its head there was nothing to bind the plates together. Thus for all commercial purposes, and where anything like good quality of iron was used, punching would still appear to be preferable to drilling.

Mr. **Vernon** concurred in the value of punching as a test of the quality of the iron, and did not think the substitution of drilled holes would be attended with any great advantage in iron shipbuilding. He showed two sections of plates rivetted together, one with punched holes and the other with drilled holes, from which it was seen that the rivets filled the punched holes quite as well as the drilled holes; and he therefore concluded the rivetting would not be benefitted by drilling the holes instead of punching them. Certainly punching was a quick and ready means of ascertaining the quality of the iron by examining the holes made and the burrs punched out: if the iron were brittle or inferior, the burrs would be much starred, showing the grain of the iron disrupted by punching; but if the iron were of a good tough quality, the burrs kept sound and showed no disruption of the metal. There was certainly some convenience in the slight countersink of punched holes, for giving greater security to two plates rivetted together with the small ends of the holes inwards: but this would not be the case with three such plates rivetted together, where there would be an undesirable enlargement of the rivet hole at some one part, causing a tendency rather to push the plates apart in the act of rivetting than to draw them together; and in practice therefore where three or more plates were rivetted together with punched holes it was necessary to pass a rimer through the holes, to get rid of the slight taper and make them more nearly parallel.

Mr. W. **Richardson** thought it would be rather retrograding in mechanical principle if drilling instead of punching were not persevered in for rivetted work, and even extended in application. The simple question was whether rivetted plates were any stronger with punched holes than with drilled holes, and his own opinion was that the reverse was the case; and certainly if the iron of the plates were of inferior quality in any instance, it would be better then to drill the holes rather than to punch them, in order to avoid as far as possible putting any strain on the metal. As to the advantage of the conical holes obtained by punching, the countersink could readily be made in drilling by using a countersink or slightly conical drill; but with punched holes crooked rivets must inevitably occur, since it was impossible to get the punching done with such accuracy as to ensure all the holes being truly in line with one another in the two plates rivetted together.

Mr. J. J. **Birckel** had known some experiments made on punched plates by a member of the Institution, Mr. W. Anderson of Dublin, in which it had been found that the iron was considerably deteriorated in strength by punching the holes, as compared with drilling them.

Mr. **Vernon** said that although the act of punching must of course be to a certain extent injurious, by throwing some strain upon the iron surrounding the hole, yet it was found in practice that, by properly proportioning the welt or overlap of the plates, excellent joints were made in rivetted work with punched holes, and the work so rivetted was not deficient in strength at the joints compared with other parts. As to the relative value of punched holes and drilled holes, he was not able to express a preference for either as absolutely superior to the other, and could merely state that from present experience the drilled holes for rivetting did not appear to have any advantage over punched holes for the purposes of iron shipbuilding.

Mr. J. McF. **Gray** remarked that the experiment which had been described as to the relative strength of wood and steel spars showed that, when the spars were exposed only to the strains produced by dead weights, their strengths were as two to one. But the disparity of strength would have been found much greater if the spars had been tested by blows by a weight falling from a height, instead of by a dead weight simply resting on the spar. In practice more breakages were caused by a sudden blow or jerk, as in the case of a chain riding and slipping a link, than by any steady pressure or strain upon the spar. He enquired how much heavier the steel spar would have to be made, in order to be as strong as the wood spar in withstanding a blow.

Mr. **Vernon** replied that he had not attempted testing the spars by the blow of a falling weight, but had loaded them with gradually increasing weights, as described in the paper, until they broke under the load. He had not ascertained the weight of steel that would be required to make a spar as strong as the wood spar had proved: but in addition to its greater strength the superior elasticity of the wood spar was certainly remarkable, the deflection amounting to as much as 41 inches or nearly 1-16th of its length immediately before breaking under the load of 8 tons, whereas the steel spar deflected only 4¾ inches or less than 1-8th of the amount before breaking under 3⅝ tons load.

The **Chairman** observed that among the sections of iron now employed in the construction of iron ships there were some of very large size, as shown in the drawings exhibited, and he enquired where the rolling of such large sections was carried on, some of them being as deep as 16 inches and 60 feet long all in one length.

Mr. E. **Reynolds** said he had seen solid rolled beams 12 inches deep with flanges 5 inches wide at top and bottom, and believed some rather larger sections had been attempted in France; but that appeared to be the extent to which the rolling could be carried at present, as such a depth of section made it necessary to start with a pile of extravagant dimensions, and to have a large number of grooves in the rolls to reduce the thickness of the metal very gradually; because in the process of rolling those large sections each passage of the iron through the rolls would reduce the middle web perhaps 20 per cent. in thickness, while the top and bottom flanges would be reduced only 5 per cent., causing an undue stretch on the flanges which tore them unless the irón were very good; so that great practical difficulty was experienced in rolling the girder sound. He had seen the large beams made at Butterley for the "Warrior," 16 inches deep and 60 feet long; but those could hardly be called solid rolled girders, being almost as much built up as if they had been rivetted; they were built up of two T irons, each made of two or three lengths welded together, forming respectively the upper and lower half of the girder, and these were then welded together along the centre of the web throughout the entire length, a special bar of H section being inserted between the upper and lower T irons and clipping the edges of both, the heating being accomplished by moveable fires and the welding by hammers striking simultaneously on opposite sides, welding the different portions of the whole length successively. Great difficulty had been experienced in accomplishing this at first, but now the process was successfully managed: and the T irons were easily rolled of large dimensions, for by passing them edgeways and flatways successively through the rolls the work done upon the iron by the rolls was equalised throughout the entire section of metal. Girders manufactured by this plan had been shown at the Exhibition of last year, 4 feet deep with flanges 9 inches wide; and it was clear that was by no means the limit of size if beams were built up in that way by welding.

Mr. T. W. **Plum** said he had superintended the rolling of the large rolled beam shown in last year's Exhibition, 12 inches deep with top and bottom flanges 5 inches wide, which was rolled at the Blaenavon

Iron Works in one solid section; it was passed through only five grooves in the rolls after leaving the roughing rolls, and was upwards of 40 feet long and 1 ton weight; though not so perfect as it might have been with further experience, it was the first beam rolled of so large a section and so great length. A large quantity of beams of the same section but shorter lengths had since been rolled at Blaenavon, and there was no real difficulty in rolling beams of that section as long as 60 feet in a single length. It was merely a question of the extent of furnace accommodation that was available for reheating, since such a section of beam would require reheating three or four times during the operation of rolling. In the formation of the pile for these heavy sections it was quite necessary to have a shaped pile, built up into something of the shape of the ultimate section required; otherwise sixteen or seventeen grooves in the rolls would be needed for working it down gradually to the finished dimensions. The outlay necessary for producing such work was too great to make it commercially profitable, unless the demand were large. The welding process employed at Butterley, as had been described, would no doubt make good work; but he thought that, as the demand increased, beams rolled all solid would be produced of still larger sections and greater lengths than had yet been done.

Mr. **Vernon** said he had not found in practice that such extraordinary lengths of beams were required according to the present construction of iron ships. The introduction of the forms of iron deck beams shown in the sections, Plate 38, was due to his late father and Mr. Kennedy; they had proved very successful, and their adoption had now become universal in iron shipbuilding. The several sections of iron shown in the drawings were those actually used in ships at the present time; but probably no limit could be assigned, as far as the requirements of deck beams were concerned, to the sections and lengths that would hereafter be produced by rolling.

Mr. **Maxwell Scott** observed that in the section shown of the ordinary construction of iron ships there did not appear to be any box girders rivetted on either side of the hatchways on the upper deck, running the length of the vessel, which would add materially to the strength; and he enquired whether the strength of the iron ships was found by calculation to be sufficient without these, and whether the section as shown was all that was required by Lloyds' rules.

Mr. VERNON replied that box girders rivetted on each side of the hatchways in the decks were certainly a great advantage to the strength of the upper portion of an iron ship, preventing the decks from being at all weakened by the holes left in them for the hatchways. But he had not shown any girders at those parts in the section of vessel exhibited in the diagram, as that was intended to represent only the actual strength of iron vessels as at present built in accordance with Lloyds' rules, which did not require any provision of box girders alongside the hatchways. Many iron ships of that size, 1200 tons burthen, carried their cargo over long voyages without suffering any injury from the absence of this provision; but in larger vessels he considered the box girders at those places would probably be needed for the safety of the ship, in addition to the usual box stringers added to the decks of large ships.

The CHAIRMAN remarked that it appeared from the calculations given in the paper that the main defect in iron ships as at present constructed was a deficiency of strength in the upper portion, and he believed several instances had occurred of iron vessels having their decks seriously strained in severe weather, and even their sides partly torn at the top, for want of the additional strength at that part which would be obtained by box girders along the deck.

With regard to the comparison between the wood and steel spars, the results obtained from the experiment were certainly very remarkable, as it would have been expected from all former experience that the steel spar would show a greater amount of elasticity. There was some doubt however, it appeared, whether the metal had not been strained previously in the manufacture of the steel spar; and he thought the place at which it broke indicated this, the breakage having been first at a point only 6 feet distant from the end of the spar. The saving of weight obtained by the substitution of steel masts and yards would be a great benefit to the sailing of the ship; but in the steel spar experimented upon there seemed a deficiency of material, and the reduction of weight had perhaps been carried rather too far in that particular instance. A more important consideration however in practice than the ultimate breaking strength of the steel spar was its safe elastic limit; because practically the object to be aimed at was that the spar should be made so strong as never to be likely to receive any permanent set from any strain that it might be expected to meet with in the ship. The great advantage of steel in this respect had he understood been found by Mr. Mallet to be that its safe elastic limit was very high compared with that of iron: and in order to make the comparison complete, he would have wished, had it not been for the great expense of the experiments by the breakage of such costly spars, that a third spar of iron had been tried in the same way as the wood and steel spars, and all three of them in reference to the safe elastic limit of each.

Mr. **Vernon** remarked that, in reference to the deficiency of strength which had been shown to exist in iron ships from the want of longitudinal box girders in the decks, he had endeavoured rather to arrive at a clear and tolerably accurate comparison of the relative strength of iron and wood ships under the two extreme circumstances to which they might be exposed, than to establish the superiority of either or to advocate any particular mode of construction in preference to others for the iron ships. The general result he had arrived at, as stated in the paper, was that if a ship were supported in the worst position for its strength, namely at the two ends, the iron ship would be about one eighth deficient in strength and the wood ship one sixteenth deficient; whereas if supported in the middle, the iron ship would have an excess of strength of one eighth and the wood ship an excess of one sixteenth.

In the steel spar that had been experimented upon it seemed curious that the point where the breakage first occurred should be so near the end of the spar; but it must be mentioned that the longitudinal steel angles rivetted along the inside of the spar, as shown in the transverse section, Fig. 45, Plate 43, terminated about one foot short of the point of fracture, and therefore the spar was defective in construction, having a sudden change of strength at that place. The experiment on the two spars had certainly been a very costly one, and he would have hesitated to undertake it but for the fact that no experiment on a reduced scale would have been satisfactory in disclosing whether the course now being pursued in the construction of steel spars was a safe one. The subject was felt to be one of so great practical importance that one gentleman engaged in the manufacture of steel had liberally offered to repeat the experiment on the steel spar at his own cost, in order to obtain a result free from any doubt as to the quality of the material employed and the perfect construction of the spar. Although the present experiment showed that the steel spar was inferior to the wood, it did not determine whether this was due to an inferior quality of material being used for the steel spar, or whether a spar made with the same weight of good steel would still be weaker than the wood spar. He therefore hoped to be able before long to give the results of further experiment on the subject, that a satisfactory conclusion might be arrived at, enabling iron shipbuilders to make steel spars of equal strength with the best wood spars.

The **Chairman** moved a vote of thanks to Mr. Vernon for his paper and the valuable information he had supplied, which was passed.

The following paper, communicated through Mr. John Pearson, was then read:—

ON THE EFFECTS OF SURFACE CONDENSERS ON STEAM BOILERS.

By Mr. JAMES JACK, of Liverpool.

Some three or four years ago condensation of the exhaust steam from marine engines by surface contact was looked upon as an experiment, and few steam ship owners could be induced to try this system, which was new to them: and notwithstanding the development and complete success of tubular surface condensers, both in merchant ships and in the navy, more than a quarter of a century ago, and the reduction thereby effected in the consumption of fuel, the objection was raised that surface condensation could not have the advantages alleged, or it would never have been discontinued. At the present time however it is no longer an experiment, but a reality: for not only have surface condensers been largely introduced with new engines, but in many cases injection condensers have been taken out of working vessels and surface condensers put in their place. As the writer's firm has constructed and fixed a considerable number of surface condensers during the last three or four years, and as certain actions have been found to take place on the tubes and plates of the boilers with these surface condensers, of such a character that the full advantages of the use of distilled water could not with impunity be obtained, it is the purpose of the present paper to give the particulars of these effects. The effects produced upon boilers where surface condensers are used must have been noticed by many engineers, and the object of the paper is therefore to induce discussion upon the subject and elicit information which will enable the great advantages in the saving of fuel resulting from the employment of surface condensers to be realised. As the boilers where surface condensers are used are insidiously and rapidly acted on, the danger of delay and of accident from explosion is thereby greatly increased, rendering the question one of serious importance.

Surface condensation may be considered an old idea: for Savery adopted the principle in 1698 in what may be called the first steam engine, having applied cold water to the outside of the cylinder; and even Watt devoted much time to it, although he afterwards finally abandoned it, stating that the objection of the size and expense of the tubular condenser for large engines made him resolve to sacrifice part of the power to convenience, and to employ large pumps. It was about 1832 that surface condensation became practically carried out. Mr. Samuel Hall having seen its advantages constructed a surface condenser consisting of a casing containing a number of small tubes; and succeeded in overcoming the difficulty of making a tight joint between the water and steam spaces, which should allow for the expansion and contraction of the tubes. These condensers were introduced into both naval and mercantile ships; but although attended with considerable advantages they ultimately fell into disuse. Several modifications have since been proposed with different arrangements and constructions of the tubes, with the water inside instead of outside the tubes, or with a combined jet and surface condensation. There was a difficulty at first in obtaining some effective packing for the ends of the tubes: but after the long experience of india-rubber for the purpose it may now be pronounced a success; for out of many thousands of joints which the writer's firm have made, not a single case of leakage has occurred.

Surface condensation is a process by which both the sensible and the latent heat of the steam are conveyed away; and although the adoption of any new system is necessarily slow, the writer does not doubt but that surface condensation will ultimately entirely supersede the jet. There are evils however which require remedying before surface condensation can be universally adopted for steam ships; not in the condenser itself, but in the effects produced on the boilers by distilled water or something contained in it resulting from surface condensation. The writer will accordingly refer first to the effects of surface condensation on the boilers, and secondly to the probable cause of this destructive action.

A number of marine boilers which have come under the writer's observation, and may for convenience be distinguished by the letter **A**, had been in use for longer or shorter periods, none less than six months, supplying steam to engines having injection condensers. Salt water had been used for feeding the boilers, and a considerable incrustation had consequently taken place. Without going to the trouble and expense of cleaning these boilers, they were sent to sea immediately after the surface condensers were fitted in. Everything went on satisfactorily, and on returning from the first voyage the boilers were examined. It was found that the greater portion of the incrustation had fallen off, and that the surfaces of the boilers, that is the inner surfaces, were in very good condition for transmitting heat, showing that the adoption of distilled water for feed had been advantageous. Boilers of this class have uniformly had the incrustation nearly all removed by the action arising from the use of the surface condensers during the first voyage, and in every case the surfaces of the boilers have been found in good condition and still remain so, some of them now for as long a term as four years. Indeed surface condensation has here been in every sense a decided success.

The appearance of the inside of the boilers however was not that of clean iron. The surface seemed to be impregnated with some greyish matter, or to be altered in its chemical nature. That this impregnation or alteration of the surface prevented and still prevents injurious action on the metal will be gathered from a description of another lot of marine boilers, distinguished by the letter **B**, which were in all cases new boilers, sometimes with new engines and surface condensers, in other instances with old engines and new surface condensers. In port, before starting, a number of these boilers were filled with fresh water, while another number were filled with salt water. An examination after the first voyage, during which only distilled water had been used for feeding the boilers, showed the following effects, which were increased in every subsequent voyage, until the practice was adopted of feeding with say from one sixth to one tenth of salt water. First, both above and below the water line the surfaces of the plates, tubes, and rivets were covered with a deposit resembling hydrated oxide of iron, which when the water was evaporated was in the state of a fine impalpable brownish coloured powder. This deposit was thickest above the water line, sometimes averaging ¾ inch thick. When the boilers were emptied a thick slimy deposit adhered all over the inside, an analysis of which showed that it consisted of

Oxide of Iron	77·50
Moisture	19·75
Grease	0·85
Sulphate of Lime	0·80
Oxide of Copper	0·60
Traces of Alumina and Chloride of Sodium and Magnesium	...
Loss	0·50
	100·00

Secondly, underneath this deposit the plates and tubes were found to be eaten into, indented, or "pitted." The indentations varied in diameter from the smallest speck to ⅝ inch, and in depth from the merest impression to the entire thickness of the plates or tubes. And although they were formed all over the boilers, they were most frequently found and were most numerous just over the fireplaces, and in those parts immediately in connexion with the greatest heat. In some of these parts the surface was entirely covered with the indentations; while in other parts as much as a square foot of plate, although subjected to the greatest heat, was free from them. The plates and tubes in all cases have been of the best iron and by good makers, and the "pittings" occur in what looks like iron of good quality with a good fibre, no slag or cinder being perceptible. So destructive was this pitting in boilers using the same water over and over again, that in one instance the tubes of new boilers were actually eaten through at the end of two or three voyages, extending over only a few months altogether, and it became necessary to put in new tubes, and to use a portion of salt water for feed to keep up an incrustation, so that the boilers should not be acted upon. If the iron of the boilers had been all of one make, it would naturally have been concluded that the pitting was due to the quality of the iron; but as the iron of different boilers had been obtained from different makers from time to time, the quality of the iron could not be blamed.

The presence in the boiler of a soft metal, such as copper from the condenser tubes, it was considered would induce a galvanic action such as might affect the iron in some way. But the analysis which was made of the deposit scraped from the boiler shows that there was scarcely a trace of any foreign metal there. Indeed it might have been concluded that a soft metal could not be present, for the tubes of the condenser and the copper pipes were all in a perfect condition. Even at the joints, made tight by india-rubber hardened by vulcanising, there was scarcely a speck of corrosion.

A search was then made to ascertain whether the gluey deposit was present that arises from the decomposition of the tallow and oil used for lubrication; as the writer had frequently heard that such a deposit took place in boilers where Hall's surface condensers were used. For the purpose of ascertaining this the mud cocks of a vessel were not opened for some time before arriving in port; and the fires were then put out on arrival and the mud discharged, when the only substance found was the watery brownish deposit before referred to. The deposit remaining in the bottom of the boiler was carefully examined, but here again there was only the same deposit. As it was believed that the lubricating material carried into the boilers with the feed might by continued subjection to heat form an acid capable of producing the effects observed, the kind of lubricating material employed was noticed, in order to ascertain whether animal or vegetable oils acted most injuriously; but it was found that the action went on as much with the one oil as with the other. In case however a fat acid, formed as already mentioned, might be the cause, pieces of chalk were put into the boilers, and from time to time fresh pieces were added; carbonate of soda was also mixed with the feed water in regular doses: but all to no purpose, the action went on getting worse and worse.

No other alternative was therefore left, nor is there at present any other as far as the writer has been able to learn, but to feed the boilers with a portion of salt water sufficient to keep a thin incrustation over the surface of the iron. It was suggested that the deposit was nothing else than rust or oxide of iron, and that it was formed by the chlorine present in the small proportion of salt water, which would combine with the iron to form chloride of iron; and this being readily decomposed by oxygen, oxide of iron would result. The difficulty here however was to know whence the oxygen was obtained; for the quantity of air entering with the feed water must have been very small indeed. It was also suggested that hydrochloric acid might be present from the small quantity of sea water that may have found its way into the boilers; but then the difficulty was to know where a quantity of the acid was to come from sufficient to act over such an extended surface, and so rapidly as the results showed.

It was found however by Mr. Rollo, one of the writer's partners, that in a pair of boilers at a sugar refinery there was the same brownish deposit adhering all over the boilers, and those parts subjected to the greatest heat were "pitted" in precisely the same manner as the second lot of marine boilers previously designated by the letter B. Exactly the same effects were being produced. These boilers were supplied with the same water over and over again, a small quantity of fresh water being added from time to time to make up for the loss. As the steam was passed only through iron pipes for melting the sugar, the damage to the boilers could not result either from the steam coming in contact with a soft metal, or from any lubricating material. The boilers were of the Cornish construction with one flue, and were worked at about the same pressure as the marine boilers B already referred to, say 20 lbs. per square inch pressure. A pair of boilers of exactly the same construction, placed alongside the first pair and working at about the same pressure, but fed with water which had not been distilled, were then examined to learn what state they were in. But although put in about the same time as the two first examined, these boilers were found in good condition and likely to last for years, as there was not a sign of corrosion or "pitting;" whereas the two boilers working with distilled water had to be repaired.

The practical knowledge thus acquired necessarily led to the conclusion that the distilled water itself was the cause of the corrosion, instead of any galvanic action or any fatty acid. In reference to the question whether distilled water has any particular action on metals, the chemist Berthier found that nodular protuberances deposited on iron pipes containing distilled water consisted of 21 per cent. of protoxide of iron, 58 per cent. of peroxide of iron, 5 per cent. of carbonic acid, 14½ per cent. of water, and 1½ per cent. of silica. The iron pipes contained also a pulverulent substance, which could be produced at pleasure with distilled water to which a trace of carbonate of soda and common salt had been added, but not with an addition of caustic alkali. Distilled water is known to act powerfully on lead, and this action is attributed by Dr. Clark to the remarkable property that distilled water has, as compared with ordinary water, of dissolving free carbonic acid.

The writer does not presume to state confidently that distilled water is really itself the active destroyer of iron boilers; but, from the observations that have now been referred to and the information he has been enabled to obtain, he thinks there is sufficient evidence that distilled water is, if not the sole cause, at least an active agent in producing the corrosive effects that have been described. If this suggestion should lead to the remedy of the evils that have been experienced where distilled water alone has been used, another difficulty will have been overcome towards the complete introduction of surface condensers.

Mr. J. **Ramsbottom** said he had been much interested in the paper just read, and the conclusions arrived at coincided with the results of his own experience with stationary and locomotive engines, not with distilled water indeed, but with peat water which was almost as pure as distilled water. He had been informed that the boiler of the winding engine which formerly worked the Woodhead Tunnel on the Sheffield and Manchester line was corroded through in a very short time, being fed exclusively with the peat water from the Yorkshire moors; and on putting down a second boiler in its place the precaution was taken of mixing with the peat water a portion of water from one of the shafts, the result of which was that the corrosion was almost stopped, but an incrustation of deposit was then formed inside the boiler. In the same range of hills he found that the locomotives working the Huddersfield and Manchester line with almost pure water had their boilers corroded in the same way; and he had now adopted the plan of putting a portion of carbonate of lime in the tanks, to prevent the corrosion.

Mr. C. **Markham** had also found the use of nearly pure water injurious to boilers, and the evil effects continued until the interior of the boiler became sufficiently coated with calcareous matter to prevent the corrosion going on. The effect produced by using pure water in boilers that had previously been worked with water containing a great quantity of lime was very remarkable: some of the locomotives on the Midland Railway were supplied with water that contained much lime, causing a great deposit in the boilers; and when any of these engines were sent down to Sheffield, where the water came from the moors and was very pure, the effect of the change was that the deposit was speedily removed in large masses, and he had seen a barrowful of the calcareous matter removed and washed out of a locomotive boiler after it had worked for a single day with the Sheffield water. So long however as an incrustation of lime remained on the plates it had the advantage of protecting them from any injury by corrosion from purer water.

Mr. J. McF. **Gray** thought the "pitting" observed in the case of locomotive boilers working with pure water was due to the brass tubes used in the boilers: for on examining the pitted plates by the microscope he had detected a minute speck of brass in the centre of so many of the "pits" as he thought would warrant the conclusion that this was the cause of all the pitting, in consequence of the galvanic action produced by the particles of brass. The corrosion of the iron had accordingly been prevented in those cases by suspending a piece of zinc among the boiler tubes, which neutralised the action of the brass. The pitting had not been so extensive in the hottest plates of the boilers as in other parts, because at the hottest parts the ebullition of the water was more violent, so that there was less facility for the particles of brass becoming deposited there upon the plates to cause the corrosive action. From the paper it appeared not to be expected that distilled water would be able to be used successfully in boilers: but if the difficulty arose merely from the water used being distilled water, it might easily be got over by aerating the water, since the only difference in distilled water was that it was not charged with air like ordinary water. The real objection he considered to surface condensation was that the same water was then used over and over again without change; and he thought this must be the reason of the corrosion observed in the boilers of sugar refineries, the steam being condensed over the surface of the evaporating pans, whereby the water became in course of time impregnated with particles of brass or copper from the pans and pipes, gradually accumulating in the unchanged water. In the sugar plantations of the West Indies, where there was a difficulty in getting fresh water and the same had to be used over and over again, the water was found to get sour, as it was termed, and became more and more injurious to iron the longer it was used without change. He therefore thought the corrosion observed was to be attributed to the specks of brass carried into the boiler by the water where there was surface condensation of the steam.

Mr. D. Rollo observed that the object of the paper was not to discourage the use of surface condensation, but to point out the difficulties that had been met with in its application, with a view to ascertaining how they could be removed. With regard to the boilers at the sugar refinery that had been referred to, the corrosion could not he thought have been caused in that case by the presence of brass particles in the water; for the steam passed only between the two cast iron plates of the evaporating pans, and when condensed returned again to the boiler, without coming in contact with any brass at all in the apparatus, the leakage being made up by the addition of a little fresh water. There were four boilers all working together, two fed with the distilled water returned from the evaporating pans and two with fresh water: the two latter at the time of examination were found in perfect condition after four years' work, having only a large deposit or scale of lime over the surface of the iron; while the other two fed with the distilled water, after the same time of working, had become quite unsafe from corrosion and had to be very extensively repaired. They had tried various remedies for the evil: suspending zinc plates in the boilers, but with what result had not yet been ascertained; cast iron pipes instead of copper pipes for conveying the steam; and tinned tubes, zinc, and galvanised iron tubes in the condensers, instead of brass. Block tin tubes had also been tried, but were found not to have strength enough to support their own weight when placed horizontally. All these trials therefore still left the question of the cause of corrosion undecided: but he thought it could not be the action of copper, because the analysis that had been made of the deposit found in the boilers using surface condensers showed a very small proportion of copper, the main metallic ingredient being iron, and there was not sufficient copper collected from the boilers in the voyage of a steamship to account for such an extent of corrosion as was met with. Where much grease however was used in the engine he had seen the inside of a boiler present an appearance which he thought rendered it just possible that the fatty matter or acids contained in the grease had something to do with deteriorating the quality of the water and causing its corrosive action.

Mr. H. W. **Harman** thought the pitting of the iron plates of boilers was not to be attributed to the presence of brass or copper tubes in the boilers, because he had known the pitting as a common occurrence and extremely marked where the boilers were entirely of iron and there was no brass or copper near, so that no particles of those metals could have got deposited in the boiler. In the immediate neighbourhood of Manchester he had seen examples of extensive pitting near the surface of the water in the interior of boilers using the town water; and it was remarkable that in some cases the alternate plates only were pitted, while the intermediate ones remained altogether untouched.

Mr. I. **Smith** concurred in considering the corrosion could not be solely dependent on the presence of brass or copper in boilers. About ten years ago he had erected a hot water warming apparatus at a house near Birmingham; and three or four years afterwards, on taking up the pipes in order to extend the circuit to another place, he found the whole of the wrought iron pipes gradually corroding away and lined inside with a thin layer of black oxide of iron, though the cast iron pipes were not injured at all. In this case not a particle of brass or copper pipe was employed in any way about the apparatus, but the boiler was fed with rain water collected in the country and therefore nearly pure. The boiler was then emptied, and refilled with pump water containing a little carbonate and sulphate of lime; and on examining the apparatus again two years later he found that no more corrosion had taken place. At Messrs. Mason and Elkington's copper works at Pembrey in South Wales they had recently erected a surface condenser with cast iron pipes of 4 inches bore, and the boilers were fed with brackish pit water close to the sea, but not altogether salt. There was no brass or copper near the condenser or boilers, except the brass steam valves, the water valves being all of iron; and he should look with much interest for the results after the surface condenser had been at work for some length of time.

Mr. G. A. **Everitt** stated that two years ago he had made a large quantity of brass tubes for surface condensers of marine engines, and some time afterwards a large proportion of the iron tubes from the boilers belonging to them were shown to him, not only pitted but actually eaten through in large holes, which was attributed to the condensers having contained brass tubes. He believed this to be a mistake however, and that it was not the use of brass tubes in the condensers which caused the corrosion; and he enquired therefore whether the boilers referred to in the paper now read were ordinary flue boilers or boilers with tubes. The metal best adapted for the tubes of surface condensers did not appear to have been yet determined upon: brass had been used for a considerable time, and copper was now being tried. Experiments were also being made with electro-plated tubes, but these were so very expensive that they were not likely to come into general use: and brass tubes coated with tin had been tried, but were also expensive. Block tin and zinc tubes he had found did not keep straight when placed horizontally, as had been already mentioned; and white metal tubes were difficult to produce hard enough for the purpose: in fact it was difficult to produce any tubes so hard as the brass tubes, and at present the question appeared to lie mainly between brass tubes and copper tubes. The subject was daily becoming one of wider importance, and he considered the writer of the paper had done much service in bringing forward the results of his own experience with surface condensers.

Mr. J. **Kennan** asked whether any experience had been obtained from the use of surface condensers with boilers having steel tubes, as to whether the steel boiler tubes were injured by the water in the same way as the iron boiler plates. He thought it appeared not unlikely that steel boiler tubes might be exempted from the corrosion: for where the iron plates were coated with a hard crust of lime the injurious action was retarded, and therefore it seemed probable that at the temperature of the water in the boiler the carbon contained in the steel might protect it similarly from injury.

Mr. E. **Reynolds** observed that in the discussion upon surface condensers at the London meeting of the Institution last year it was pointed out that the corrosive action on the boiler plates was possibly owing to the grease brought over into the boiler by the steam condensed from the engine, where surface condensers were used; and that it was necessary to change the water in the boiler frequently, in order to prevent this injury. The pitting of the boiler plates had been observed in the earliest instances of using surface condensers, and was the first cause for abandoning surface condensation, and there was also the objection that the boilers were more liable to prime: he understood it had been found that in some of the marine engines fitted with surface condensers the boilers were now liable to prime very much, but he was not aware whether this was to be attributed to the surface condensers. It had been shown he believed by Mr. Grove that the act of boiling ordinary water was not merely the conversion of that water into steam, but that the bubbles of steam appeared to consist of some well-defined free gas, frequently pure nitrogen from the air contained in the water, surrounded by an envelope of steam: hence when the same water was constantly returned to the boiler and repeatedly boiled, it might be expected to become changed in the course of time and might lose its original innocuous character.

Mr. D. **Rollo** explained that in all the vessels they had fitted up with surface condensers, more than 25 in number, the boilers had been tubular boilers, all with iron tubes, excepting only one or two cases where brass boiler tubes were used; and in all cases the condenser tubes were brass. With regard to steel boiler tubes he had seen them tried and with no better results than the iron tubes; indeed in some instances they became corroded rather quicker than iron tubes, but whether that was owing to the additional carbon contained in the steel he could not say. He was satisfied however that priming had nothing to do with the use of surface condensers; because in no case had they had to make any alteration in the boilers after applying the surface condensers, nor had the priming ever been found to be worse after the surface condensers were applied than it had before been with the jet condensers previously used with the same boilers. If the boilers had plenty of steam room, he had found there was not any danger of priming; but if that point were neglected and the roof of the boiler were low, water would get carried over into the cylinders along with the steam. In support of the theory that the water underwent some change by the repeated boiling where surface condensers were used, he understood it was found that fresh water after continued use in that way carried the salinometer higher than salt water, showing that it had then become denser than the salt water used in marine boilers was generally allowed to get before changing.

Mr. B. **Poole** said they had made experiments with fresh water instead of salt in the marine boilers of the Wallasey ferry boats, and found it very successful in conjunction with surface condensers; and he could confirm the statement made as to the greater density of the fresh water after continued working.

Rev. A. **Rigg** remarked that where priming was observed in connexion with surface condensers it might probably be explained by the greatly increased coherence of the particles of distilled water, owing to the expulsion of the air contained in it by evaporation in the process of distillation, in consequence of which it was well known that distilled water boiled with great violence. In regard to the corrosive action accompanying surface condensation, there seemed reason to think that particles of the water might become decomposed in contact with the iron boiler plates into the constituent gases, whereby the iron would be oxidised without any action of brass or grease or any other foreign matter contained in the water: and the remedy would then be merely to devise a means of coating the surface of the iron so as to prevent its oxidation, as it was found the corrosion did not occur where the iron plates were protected by a layer of deposit.

Mr. J. MACKAY suggested that, as the corrosion attending the use of surface condensers was more rapid he believed on cast iron than on wrought iron, a heating apparatus of cast iron pipes might be attached to boilers working with surface condensers, for heating the feed water; and then any particles of brass or copper coming from the condenser would be deposited in the heating apparatus, and any other corrosive properties of the water would be expended on the cast iron pipes: thus the injurious effects of the distilled water would be mainly confined to the heating apparatus, and the boiler would consequently last longer. Moreover the durability of a boiler was affected by the position at which the feed water was introduced, and if the feed were at a place where the water was comparatively still the boiler would not suffer so much from corrosion or from deposit; and where the heat was properly distributed, so that one part of the boiler should not be hotter than others, a boiler would stand longer without injury. He knew of a boiler in a steamer that had been working for more than eleven years with a jet condenser, and the plates and tubes were still in almost perfect condition, in consequence of observing these precautions. Where there was any brass or copper for the steam or water to come in contact with, he thought there could be no doubt that particles of these metals must get carried into the boiler by the water, unless they were arrested on the way by some such plan as the feed-heating apparatus he had referred to.

The CHAIRMAN remarked that there seemed to be two theories suggested to account for the corrosion experienced in boilers working with surface condensers: first that a certain galvanic action was produced by particles of brass or copper carried into the boiler by the water from the condenser tubes, whereby the plates were corroded wherever a particle of those metals was deposited; and secondly that acids produced from the grease brought over from the engine might have the deleterious effects that were noticed. In favour of the former theory, that the galvanic action occasioned by brass or copper caused the injury, was the peculiar shape which the corrosion assumed: it was not shown by a regular thinning of the plates, but they were pitted in particular spots, whilst the iron in the immediate neighbourhood was as thick and as good as ever; whereas if some acid had been acting on the plates it would be expected that the action must have been more uniform, and extended over the whole surface, instead of being concentrated at particular points. If the use of brass or copper tubes in the surface condensers had been the cause of corrosion, he suggested that the plan of Mr. Lamb's boilers, with a number of flat flues of iron plates exposing a large extent of surface, might be efficient for surface condensers also, to avoid having any brass or copper at all in their construction. He had himself experienced corrosive action in a number of boilers which had no brass work about them except the steam valves and valve boxes, and on certain portions of the iron plates a corrosion took place exactly like what had been experienced in the cases already described. One boiler in particular was attacked out of a set of 25, and for a considerable time the corrosion could not be accounted for. The corroded iron plates were removed and steel plates substituted for them, but these also were eaten away and pitted exactly in the same manner. Then the water was changed, and fresh water was used from the town supply or from a well; this was constantly changed, so as not to use the same water over and over again, and new steel plates were put in to replace the corroded ones. In this case no amount of acid could be formed from grease, because there was no grease that could get near the boiler, except a little oil to keep the donkey pumps lubricated. The remedy was then found to lie in altering the manner in which the feed water was injected. The boiler was a vertical one, 30 feet high, with two large flues through it, and the feed water was originally injected at the bottom, impinging upon the flue; and the pitting of the plates took place for a length of 3 feet from the entrance of the feed. But by altering the feed pipe to enter at the centre of the boiler and furnishing it with a rose jet to distribute the feed water gradually, the corrosion was completely stopped at once. He enquired whether it had been found that there was any particular way of supplying the feed water in the boilers described in the paper, in order to diminish the corrosive effects.

Mr. D. Rollo replied that he had not found that the place where the feed was introduced in the boilers had any perceptible connexion with the corrosion: the feed pipes had been altered to different positions in several of the boilers described in the paper, and in some had remained unaltered, but without affecting the corrosion; and the corrosive action seemed to have no special effect at the parts nearest the entrance of the feed, but the pitting seized upon one plate and another indiscriminately and with considerable spaces between. Priming no doubt was affected by the position of the feed entrance; and in one of the vessels that they had fitted with the surface condensers, having round tubular boilers, much trouble had been experienced from priming, in consequence of the feed being injected too near the point where the steam was taken off; but by putting the feed pipe lower and at the back of the boiler, the priming was now got rid of completely. He did not think the corrosion of the boiler plates was caused by grease contained in the water: but it seemed more probable that by constantly boiling the same water over and over again it was robbed of some of its original properties, or became otherwise altered in quality thereby, so as to produce the serious effects that were experienced.

The Chairman moved a vote of thanks to Mr. Jack for his paper, and also to Mr. Rollo, which was passed.

The following paper, communicated through Mr. William Clay, was then read:—

ON THE MECHANICAL FEATURES OF THE LIVERPOOL WATER WORKS.

By Mr. THOMAS DUNCAN, of Liverpool.

The question of providing a supply of water for large towns has always been one of deep interest and importance, and must continue to be so. It may safely be stated that within the last quarter of a century a greater amount of mechanical skill has been devoted to the improvement of water supply than during any previous period of equal duration, especially in this country; and although much that was known and practised before has only been modified or in some instances improved, still a good deal that is comparatively new has been introduced.

In the Liverpool Water Works, forming the subject of the present paper, the supply is partly by gravitation and partly by pumping. The area over which the supply is distributed is nearly 60 square miles, and contains about 600,000 inhabitants. The gravitation portion, designed chiefly by Mr. Hawksley, is the largest although not the oldest, and has its origin amongst the hills lying between Blackburn and Bolton; the upper portion is distant in a direct line from Liverpool about 30 miles. The area from which the water is collected extends to 10,000 acres, and the greatest altitude is 1700 feet above the ordnance datum or mean low water level. The formations from which the water is obtained are the lower beds of the coal measures and the millstone grit. The average rainfall is nearly 46 inches per annum, and the quantity collected is about 75 per cent. of the total rainfall.

The general plan, Fig. 1, Plate 44, shows the positions of the several reservoirs, and the course of the pipe line throughout the entire length of the works. Fig. 2 is a vertical section taken along the course of the pipe. The principal reservoirs, shown black in Figs. 1

and 2, are formed in the valleys by embankments thrown across them, intercepting at various levels the streams which flow from the hills. The highest reservoir, the Upper Roddlesworth, is now in process of formation; and immediately below it are the Lower Roddlesworth and the Rake Brook reservoirs. From these the water is conveyed by a "goit" or open cutting down to the Anglezark and Rivington reservoirs, whence it passes to the filter beds at Horwich. The first portion of the works may be considered as terminating at this point. From Horwich the water is carried to Liverpool through a line of cast iron pipes of 44 inches diameter, broken by a short tunnel less than a mile long, and by the three balancing reservoirs at elevated points along the line—Aspull, Montrey House, and Prescot—the last being about 7 miles distant from the borough. The water is finally conveyed into the various home reservoirs for distribution. The area of the several reservoirs amounts to more than 500 acres, and the quantity of water contained in them when full is 3,000,000,000 gallons. At present about 12,000,000 gallons per day are filtered and distributed in Liverpool and the vicinity from Rivington.

The mechanical appliances connected with the gravitation portion of the works are as follow :—

1.—Slide valves in the embankments.
2.—Sluices and floodgates on the open cutting or goit.
3.—Self-acting gauges on the goit.
4.—Filter beds.
5.—Sand washing apparatus.
6.—Float valve at upper end of tunnel.
7.—Self-acting shut-off valves in the reservoirs.
8.—Reflux valves in the reservoirs.
9.—Self-acting throttle valves in the main.
10.—Escape valves on the main.
11.—Stop valves, scouring valves, and air cocks.
12.—Main or pipe line.

1. *Slide Valves.*—These are of the ordinary description. The casing is of cast iron, fitted with planed joints; and the screw spindle is of brass, working through a nut attached to the slide; a brass face is pinned on the slide, working against a brass ring pinned on the

framing. These valves are placed under all the embankments in double pairs, the spindles being fitted with stuffing-boxes and carried up through guides in the shafts, so as to be worked from the top of the embankments. The valves are nearly alike in size and character in all the embankments.

2. *Sluices on the Goit.*—Near the Rake Brook reservoir there are a pair of 3 feet square sluices on the goit, working in cast iron frames and moved by a screw spindle, bevil gearing, and crank handle. One man can shut and open these easily with a head of 12 feet on the sluices. At Brinscall Hall works there are sluices, placed in frames built in the masonry, worked in slides by rack and pinion motion, in order to allow of passing away by the original brook course such a quantity of water as will relieve the goit in time of high flood. Again at White Coppice, where the Black Brook falls into the goit, a set of three sluices are placed, worked by a screw motion. The water of the Black Brook can be caused to flow either into the goit, or over it through a wrought iron trough, as may be found desirable; and thus the water can be rejected if unsuitable, or if it be necessary to relieve the cutting in time of flood, as at Brinscall Hall.

3. *Self-acting Gauges on the Goit.*—There are two sets of these gauges on the course of the goit, one at Brinscall Row and the other at White Coppice, provided for measuring off compensation water to mill owners, giving off a stipulated quantity of water day by day. Figs. 3 and 4, Plate 45, show longitudinal and transverse sections of the gauge. It consists of a cistern fitted with inlet pipe A from the goit and outlet orifice B of notch form, as shown enlarged to one quarter full size in Fig. 5: a brass plate is fixed on the inside of the cistern with a thin-edged aperture of the exact size required, so as to give off always the same delivery of water from the cistern with great accuracy. A beam is placed over the cistern, supported on a cast iron frame, having a stone float C attached to one end and a vertical loaded copper cylinder D to the other, both adjusted by screws: the top of the cylinder D is above the high water level in the goit, and the bottom is faced to match the end of the inlet pipe A from the goit. By this arrangement the area of passage at the bottom of the cylinder D is constantly regulated by the float C to correspond with

the area of the outlet opening B, thereby providing with ordinary care for a constant quantity of water flowing off through the gauge. These gauges have been in use for about four years, and have given no trouble beyond oiling and cleaning, and have uniformly acted well. The relative levels of the gauge and goit are so adjusted that if there is any water flowing along the goit the gauge must be supplied before any portion of the water can pass further down the goit.

4. *Filter Beds.*—There are six filter beds, each 300 feet long and 100 feet wide, constructed in the following manner. The bodies of the beds are part in excavation and part in embankment, and about 10 feet deep. At the bottom of each bed are a pair of dry rubble drains, above and around which is placed a quantity of broken stone varying from 4 inch pieces down to 2 inches cube; above this five layers of gravel are laid varying in size from 1 inch to about the size of peas. On the top of the gravel is a layer of sand 30 inches deep. The water is admitted upon the filter beds by drains regulated by stop planks, and passes down through the sand and gravel into the drains at the bottom. Four air pipes are inserted into each filter over the drains, to prevent the accumulation of air; these are cast with slots in the side, over which copper wire gauze is fastened to prevent the sand passing into the pipes. The two drains under each filter bed unite together into one, and deliver the filtered water into a pit, from which a pipe communicates with the clear-water tank. On the end of the pipe within the pit a sluice is placed, worked by a screw spindle carried up to the surface; so that any filter bed may be shut off at pleasure, or all may be in work together. There are two clear-water tanks, extending lengthways across the ends of the six filter beds, with an inlet from each bed. They contain together 12 million gallons when full, and are constructed with the bottom slightly inclined towards a cleansing outlet, and sloping sides, and are paved with dressed stone. The main pipe conveying the water to Liverpool is inserted into these tanks, one branch into each, fitted with sluices, so that either of the tanks may be worked by itself or both may be used at the same time.

Any solid matter in suspension in the water is intercepted and retained at the upper surface of the sand in the filters. When any of the filter beds becomes foul and the requisite quantity of water will not pass, the supply of water is shut off from that filter and the water in the clear-water tank is lowered below the surface of the sand in the bed; the upper film of sand, generally about $\frac{3}{4}$ inch thick, is then removed and washed, and when a sufficient quantity of clean sand is prepared and the filter cleared, the sand is put on again, and the filter thus restored to its original condition. The length of time a filter will work before requiring cleaning depends altogether on the quantity of matter in suspension in the water, coupled with the quantity of water which has passed through the filter. Sometimes the filters have worked for six weeks, at other times they have not worked for more than ten days, and on a few occasions not for more than a week: fourteen days may however be taken as a mean, and the annual cost at £100 for every million gallons filtered daily. This sum provides for replacing the sand lost in the process of washing, where it does not cost more than 6*s*. per cubic yard laid on the works. The mean quantity of water which will pass through one of the Rivington filters may be taken at half a cubic foot per hour for every square foot of surface.

5. *Sand Washing Apparatus.*—The sand washing is performed by machinery, consisting of a nearly horizontal spindle with a number of spiral blades upon it, placed in a trough 12 feet long, and driven by a small high pressure horizontal engine. A stream of clear water flows into the upper end of the trough, and the foul sand is carted into a hopper at the lower end, from which it is fed into the trough by a screw driven by the engine. The screw blades on the longitudinal spindle then carry the sand forwards against the stream of water to the upper end of the trough, where it is caught by scrapers placed on an endless revolving gutta-percha belt; this works in an inclined trough and carries the washed sand upwards until it falls into shoots at the top, which convey it into wagons to be removed for use again in the filters. The head gearing on the top of the shoots is provided with extension gearing by which any lengthening of the gutta-percha belt can be taken up; and the shoots are arranged to shut or open as required, so that no sand may fall while a full wagon is being taken away and an empty one placed under them. Ten cubic yards of sand per hour are washed and loaded into carts by this machine. The idea of this machine was obtained from a small one at Crewe, designed and

constructed by Mr. Ramsbottom; the arrangements for self-feeding and loading the washed sand have here been added to the original.

6. *Float Valve at upper end of tunnel.*—The main or pipe line commencing in the clear-water tanks passes across the valley and under the Bolton and Preston Railway, and then enters a hill distant about 2 miles from the filtering works. At this point it terminates in a circular tank of brickwork at the upper end of the tunnel, into which the water is delivered, as shown in Figs. 6 and 7, Plate 46. The pipe is fitted with a sloping end piece E, on which is hinged a flap valve F, shown black in Fig. 6. When any stoppage takes place on the down-stream side, the water rises in the tank, and the floats G rise, and by means of the levers H close the flap valve F and shut back the water in the supply pipe E; until the water again falls on the lower side, when the floats fall and open the valve again, as shown dotted in Fig. 6, allowing the water to run free as before. The brick tunnel about 1600 yards long is succeeded by about a mile of pipe, which carries the water to Aspull reservoir, where it is delivered. Aspull and Montrey House reservoirs may be considered simply as relieving reservoirs.

7. *Self-acting Shut-Off Valves.*—On the outlet pipe from the various reservoirs a self-acting shut-off valve is placed, which is shown in Figs. 8 and 10, Plate 47, for shutting off the flow of water from the reservoir when a fracture takes place on the pipe line on the delivery side. The outlet pipe K has an up-turned end, fitted with a brass face, over which is suspended vertically the cylindrical valve L of the same diameter, with a brass face on the bottom, fitting the face of the pipe K. In the outlet pipe is hung a flat disc I, Figs. 8 and 9, at the end of a long lever, presenting its flat face to the current of water flowing off from the reservoir, and weighted by the weight J so as to stand still as long as the water flows through the pipe at the proper velocity. But whenever a fracture takes place on the delivery side of the pipe, the current is accelerated, and the disc I is thereby thrown forwards, as shown dotted in Fig. 8; the trigger M is thus released and thrown off, and the large suspended cylinder L descends on the orifice of the pipe K, shutting off all further passage of the water down the pipe. Alarum bells connected with the valves have recently been

fitted to each of the cottages at the reservoirs where these valves are placed, so that if the valve runs down the bell is rung to warn the keeper.

8. *Reflux Valves.*—At each of the reservoirs there is a reflux valve placed on the end of the inlet pipe supplying the water to the reservoir. This is shown in Figs. 11 to 13, Plate 48, and consists of a series of hinged doors or flaps N with brass faces, hung on the orifice of the inlet pipe, which has also brass faces slightly inclined to the vertical. The current of the water entering the reservoir keeps the flaps sufficiently open to admit the water to pass in; but whenever a fracture occurs at a point on the up-stream side lower than the water in the reservoir, the weight of the valves and the pressure of the water closes them, and so prevents a reflux of the water from the reservoir.

The above description applies to all the self-acting apparatus fitted to the reservoirs, and the only other mechanical appliance in connexion with them is the delivery well at the Prescot reservoir. This is a circular iron tank, into which the main pipe delivers the water, with a reflux valve fitted on its extremity. From this well the water is conducted into the different compartments of the reservoir by pipes furnished with slide valves, which are worked by screw spindles and bevil gearing. Any portion or all of the pipes may thus be shut off, or all the communications can be open together. An overflow pipe rises in the centre of the well, communicating with an overflow culvert carried from the well, so that any excess of water is permitted to pass away without injury to the embankments. A series of observations have been carried over many months, taken at fixed periods daily, carefully noted and compared with actual measurements of the quantity of water passing through the main between Prescot and Liverpool; so that by observing the point at which the weight stands on the lever of the self-acting valve, the quantity of water delivered can be computed and ascertained exactly.

9. *Self-acting Throttle Valves in the Main.*—One of these valves is shown in Figs. 14 to 17, Plates 49 and 50, and they are designed for a purpose analogous to that of the self-acting shut-off valves placed on the reservoir outlets, but differ considerably in construction. The throttle valve O, Figs. 14 and 16, is placed on a horizontal spindle in

the main, and on the outer end of the spindle is a wheel P carrying a heavy weight, which tends to close the throttle valve O, but is prevented from doing so by the trigger M catching the stop on the wheel P. A flat disc I, about 18 inches diameter, Figs. 16 and 17, is held in the main at the end of a long horizontal lever, presenting its flat face against the current; and as long as the velocity of the current does not exceed the proper limit, the disc is held stationary in its place by the weight J, as shown in Figs. 14 and 16, the vertical spindle on which the disc lever I is carried being geared by toothed sectors to the spindle of the weight lever J; and the throttle valve O then stands full open, presenting its edge to the stream, as shown by the dotted black line in Fig. 14. When a fracture takes place on the down-stream side, the velocity of the current along the main is increased, the disc I is pressed forwards, as shown in Fig. 15, the trigger M is released, and the weight on the wheel P of the throttle valve spindle descends, turning the throttle valve O across the main, as shown by the dotted black line in Fig. 15, and thereby entirely stopping the passage of the water. The spindle of the throttle valve is placed 1½ inch out of the centre of the valve, so that the pressure of the water may assist the weight in closing the valve. In order to prevent the throttle valve from closing suddenly, and thereby causing an injurious concussion upon the main by the sudden stoppage of the long column of water, its motion in closing is retarded by a piston working in a small water cylinder Q, the piston rod being connected to the wheel P on the throttle valve spindle. A small pipe communicates from the top of the cylinder Q to the small cistern R on the top of the main, and a second pipe from the bottom of the cylinder to the cistern; in the first of these a stopcock S is placed, worked by a lever T; and as the wheel P turns round, closing the throttle valve O, a stud on the wheel raises the lever T and gradually closes the stopcock S, as shown in Fig. 15, so that the discharge outlet from the cylinder Q is throttled, and the closing of the throttle valve O retarded. When the valve O has to be opened again, the small hand force pump U connected with the cistern R is used to force the piston down to the bottom of the cylinder Q, thereby turning back the wheel P into its original position and opening the throttle valve O; the delivery pipe from the force pump enters below the stopcock S, which is kept closed until the opening of the valve O is completed, when the whole apparatus is set again in its original working position. Owing to the use of the retarding cylinder Q and stopcock S, about three minutes are occupied in shutting the throttle valve O. These self-acting throttle valves were furnished by Sir W. G. Armstrong and Co. of the Elswick Works.

10. *Escape Valves on the Main.*—However slowly the current in a large main is stopped, there will always be practically a series of pulsations running backwards to the fountain head from which the water is supplied, their intensity depending on the velocity at which the water was moving when the stoppage was commenced and on the length of time occupied in arresting the current. To obviate the danger arising from this cause, loaded escape valves have been placed along the line of main and behind the self-acting throttle valves, as shown in Figs. 18 and 19, Plate 51. These are loaded slightly over the working pressure in the main, and communicate with some convenient water course; so that when the current is stopped by the closing of the throttle valve the escape valve is lifted as soon as the recoil reaches it, an escape of some water takes place, and so on at every pulsation, until the force of the recoil falls within the limit to which the valve has been loaded over the working pressure, whereby all danger to the main is prevented.

11. *Stop Valves, Scouring Valves, and Air Cocks.*—At various points along the main are placed stop valves, so that the water may be shut off at convenient distances for facilitating repairs. They are slide valves formed with three vertical slides, the largest in the centre, and a smaller one on each side, worked by screw spindles. A scouring outlet closed by a slide valve is also placed at each brook course or hollow where practicable, by which the pipes may be scoured out whenever necessary. On each summit along the course of the main a small air cock is inserted into it to allow the air to escape. These are simple stopcocks, with short lengths of lead pipe attached to carry off the waste water from them. It has been found advantageous to leave them slightly open, sufficiently to permit a small quantity of water to escape; this ensures a full main.

12. *Main or Pipe Line.*—The main is 44 inches internal diameter, and is for its length the largest main yet laid. The pipes are jointed in the ordinary manner with yarn V and lead W, as shown in the section, Fig. 20, Plate 51, one quarter full size; for the greatest portion of the length they are strengthened by wrought iron hoops shrunk on the sockets. Between Prescot and Green Lane an additional line of pipe is about to be laid of 36 inches diameter, with bored and turned joints, as shown at X in the section, Fig. 21, one quarter full size. These joints are bored and turned slightly conical, with a taper of about 1 in 62 on each side, and a single thread of tarred yarn is lapped round the spigot end to provide a slight elasticity in the joint; the pipes are then put together with melted asphalt Y, the socket being slightly warmed at the time for the purpose of expanding it when pressing the spigot end into its place. Experiments have been made in Glasgow, where these pipes are being cast, from which it is found that joints made in this manner resist a high pressure; and when the ground on which they are to be laid is solid, they are employed with considerable pecuniary advantages. Pipes with these joints have recently been laid at a saving of 50 per cent. in cost of laying over the ordinary plan of lead joints: and they have been used for water mains in Liverpool for several years past with perfect success. Several experiments have been made to ascertain the amount of deflection that may be safely obtained with pipes jointed with these bored and turned joints. Two pipes of 24 inches diameter were jointed in this manner, and flanges were bolted to the outer ends with holes for a pressure gauge and the pump connecting pipe. They were supported at the ends only, leaving a clear distance of 28 feet unsupported, and were then weighted with 36 cwts. on the centre, which produced a deflection of $\frac{1}{8}$ inch. A pressure of 190 lbs. per square inch was then applied by the pump, and the joint began to draw slowly, causing the pipe to sink in the centre. A deflection of 6 inches was obtained before there was any leakage, when the pressure was 160 lbs. per square inch, at which point a slight leakage commenced.

The line of 44 inch main terminates at Green Lane. At Old Swan one branch 24 inches diameter is taken off to the left, and carried to the Parkhill reservoir at the south end of the town. Another branch

24 inches diameter is carried along Green Lane to the reservoir at Audley Street for the north end. The main 44 inches diameter is reduced to 36 inches, and is carried into the Kensington reservoir. The reservoirs in town are all covered by brick arching grassed over; and from them the various distributing mains are carried.

The town is divided for the purpose of the water supply into three main divisions, north, middle, and south; and these three each into upper, middle, and lower levels. Each of these is again subdivided into sections, so that any one can be shut off without interfering with the others; and between each main division communications are made, so that they may be supplied in more than one way.

The old valves which belonged to the old water works have been nearly all removed and replaced by screw slide valves of the best make; and in nearly every instance the water supply to the several divisions is regulated by slide valves of the best kind. The connecting ferrules for the service pipes are screwed into the iron pipes, and the lead service pipes are attached without solder. Stopcocks of the best make are fixed on the service pipes in the footways to all new property, but much of the old property is still without this provision, and some years must elapse before the whole can be made uniform.

Wherever an intermittent supply of water has originally existed and a constant supply has subsequently been introduced, it has been found more difficult to reduce the quantity of water consumed to a minimum, than where the constant supply has been established in the first instance. This arises from the defective fittings pertaining to the old system, and the larger sized service pipes which were necessary to give such a supply as was given in Liverpool, namely three times per week and generally not for a longer period than 1½ hours at a time.

The hydrants for extinguishing fires now used in Liverpool are chiefly laid in the footways. They are simple slide valves with up-turned nozzles, and have screws to fit the fire hose. They are placed at convenient distances, generally in pairs, so that several sets of hydrants can be brought into play at a fire if necessary. In Liverpool engines are not generally used at fires, but the water is thrown direct from the hydrants fixed on the mains. Similar hydrants are laid around all the docks, and are used for the supply of water for shipping. Meters mounted on spring carriages have recently been introduced for the shipping-service supplies. When a vessel is to be supplied with water, the waterman wheels the meter close to one of the hydrants, a short length of hose is attached to the hydrant and the meter, and another hose is carried from the outlet of the meter either on board the ship or to casks placed on the quay. The index is taken, the hydrant opened and the supply given, when the quantity supplied is read off the index and the charge adjusted accordingly. From four to five thousand gallons per hour can be supplied in this way by one meter, and all disputes as to the correct quantity of water delivered or the size of vessels to be filled are thereby obviated. The meters generally do not vary more on either side than one per cent. from the correct measurement. A meter with its carriage complete costs about £20; and the cost of their repairs, taking the experience of three years, is 1*s.* 6*d.* per million gallons delivered.

The flushing cocks or valves are similar in construction to the other slide valves already described. They are used for flushing the sewers, and are carried from the mains at those points where the greatest length of sewer can be flushed by a single cock. An eyelet is carried up to the surface immediately over the junction with the sewer, so that any escape may be seen on inspection from the surface. A peculiar kind of cap is placed over the spindles of these valves, so that they cannot be opened by mistake; such mistakes have occurred, but have been prevented since these caps have been employed.

Up to the commencement of 1857 all the water supplied to Liverpool was obtained from wells in and about the town, sunk in the new red sandstone, the formation of the district, from which the water was pumped by steam power. Immediately before the introduction of the water by gravitation there were seven pumping stations with wells and one pumping station from a reservoir. The wells varied in depth from 130 to 200 feet. There were in all eleven engines, ten of which were generally in work at a time; only a few of these need be noticed. The accompanying Table I appended gives the principal particulars of the engines and boilers. Table II shows the cost of pumping by the various kinds of engines employed, taken over an entire year. Table III shows results obtained in testing the economic value of several kinds of Lancashire coal mixed with slack at the pumping stations, the water evaporated being measured by a meter.

At Green Lane station there are three engines. The first, by Harvey of Hayle, has been erected for sixteen years, and with short intervals of rest has been kept working ever since. The second, by Forrester and Co. of Liverpool, was erected in 1852, and has also been almost constantly at work since that time. The third was removed from Bootle Station, and after being thoroughly overhauled and repaired was put up in its present position in 1855, and has with the others been nearly constantly at work. The two first are Cornish engines, and the third a double-acting crank engine.

The pumps of the two Cornish engines are solid plungers working through stuffing-boxes. The lower plungers are worked by rods of flat bar-iron attached to crossheads at top and bottom. The length of stroke in each case is 8¾ feet, and the diameter 17½ and 19 inches respectively. Each of the lower plungers delivers its water into a cast iron cistern a few feet below the surface of the ground, into which the wind-bore of the upper plunger dips. The delivery in the case of the first engine is directly into the ascending limb of a stand-pipe enclosed in the tower containing the chimney; and in the case of the second engine the delivery pipe is attached to the bottom of the descending limb, whence an 18 inch pipe passes to the 36 inch main from Rivington, in which both waters are mingled. To the first engine an auxiliary bucket lift is attached, of larger dimensions than the plunger pump; and in order to provide for getting down to the lower plunger it is constructed to deliver its water at the surface. The valves are all double-beat, the beats being now wholly composed of gutta-percha, which has been found to suit the purpose intended better than any other material that has been tried. The pump of the third or crank engine is a single-lift bucket pump working into an air vessel. The load on the upper plungers of the two Cornish engines is about 50 lbs. per square inch, and on the bucket of the third engine 120 lbs. per square inch. The indicator diagrams obtained from the two Cornish engines with 275 feet of lift are shown in

Figs. 22 and 23, Plate 52; and Fig. 24 shows the diagram from the crank engine with the same lift.

The boilers to these engines, three to each of the two Cornish engines and two to the crank engine, are cylindrical with internal flues. The draught is carried through the flues to the back, returning along the sides, uniting and returning to the back along the bottom, and then into the main chimney flue which extends across the ends of the boilers with dampers to each boiler and to the entrance into the chimney. Each set of boilers is provided with a steam chest; and all are enclosed in brickwork, a small clear space being left both between the boilers themselves and the steam chest, and the brickwork is levelled up and flagged over. The condensing water from the engines is passed through a set of cooling ponds, and with a slight supplementary supply from the wells is used over and over again.

The wells from which these engines work are 185 feet deep below the surface, and have tunnels or drifts extending in all about 300 feet from the shafts in various directions: three separate shafts are carried up to the surface. The quantity of water yielded by this well is greater than from any other of the wells of Liverpool, being more than three million gallons daily. A 9 inch diameter borehole has been sunk below the bottom of the well to a depth of 185 feet deeper, which largely increased the quantity of water yielded. The flow from the borehole is regulated by a plug at the bottom of a long rod working in guides, which is raised or lowered by a strong screw at the top, whereby the borehole is opened or shut at pleasure. In preparing for the seat of the pumps attached to the second engine a diving apparatus was employed, and all rubbish was cleared away from the bottom; thus the difficulty of obtaining a sound good job in fixing the pitwork was greatly diminished.

At Windsor station the pumps are arranged in two lifts, the bucket below and plunger above; the first delivers the water into a cistern, the second works from the cistern and into a column or pipe with the upper end closed, acting as an elongated air vessel, with which the distributing main is connected. Originally it was intended to supply a part of the town direct from this station, and in order to meet the varying load a balance bob with a weight was applied to the engine. To remove this weight every time a change of load took place was found inconvenient, and a small line of rails with truck and screws was therefore placed over the balance bob pit, by which one man can in a few minutes make the required change. The boilers are plain cylindrical without flues, with steam chest on the top, all covered as at Green Lane. Originally much of the surface was left exposed, but now all is covered in, and the effect has been such a saving in fuel as in a short time repaid all the cost of the alterations. The condensing water is worked in a circuit through a small cooling pond, as at Green Lane. Figs. 26 and 27, Plate 53, show indicator diagrams taken from the engine at this station: Fig. 26 shows the diagram with 247 feet height of lift, and Fig. 27 is the diagram with 295 feet lift.

At Bootle station there are two old double-acting crank engines with double-acting pumps. Originally they were worked with low pressure steam; but the old wagon boilers have now been removed and replaced by tubular boilers covered over, and high pressure steam with a covered steam chest has been applied; the saving in fuel thus effected has been 30 per cent. Fig. 25, Plate 52, shows the indicator diagram obtained from one of these engines with 170 feet lift. The pumps work into air vessels, from which the mains are carried, supplying the district between the station and the reservoir; and the difference in quantity between supply and demand flows into the reservoir. The wells of Bootle yield about 800,000 gallons daily; they are about 50 feet deep. Some years ago several boreholes were sunk here, one to the depth of 600 feet below the bottom of one of the collecting wells; at first this yielded a large volume of water, but now it yields a very small quantity.

The other old pumping stations now seldom or never used are the Bush, William Henry Street, the Park, and Hotham Street. At all of these with one exception the engines were nearly alike, old and costly to work. There are two pumping stations besides, where there are no wells, but the water is raised for the supply of the high level district from reservoirs which supply the middle and low levels: these are Audley Street and Devonshire Place stations.

The Audley Street engine is Cornish, made by the Haigh Foundry Co., Wigan. The cylinder is 36 inches diameter, 6 feet stroke in the cylinder and 6 feet stroke in the single plunger pump of 19 inches diameter, which draws from a cast iron well communicating with the lower reservoir. The water is raised 92 feet into a covered tank 75 feet diameter and 10 feet deep, containing a quarter of a million gallons nearly, from which the high levels are supplied. There are no internal ties in the tank, but it is supported entirely from without at about one third of its height by wrought iron hoops and struts from the ends of the supporting girders. Self-regulating gauges are attached to the clocks in the engine house, from which traced diagrams are daily obtained, showing the hour lines and the corresponding depths of the water at any time in both the tank and reservoir. Fig. 28, Plate 53, shows the indicator diagram obtained from this engine with 100 feet lift.

At Devonshire Place station there is a small high pressure engine, possessing no feature of interest and expensive in working, which will shortly be superseded by a second Cornish engine about to be put up at Audley Street. This is to have a 50 inch cylinder with 10 feet stroke, and 29 inch solid plunger; in its general features it will resemble the engine already erected at that station.

Besides the works already described there are two small reservoirs in progress near the town; one for receiving the water direct from the main from Prescot, and an engine is being made for pumping from a well in connexion with this reservoir into the second reservoir.

TABLE I.

Liverpool Water Works.

Particulars of Pumping Engines and Boilers.

Name of Engine.	Description of Engine.	Date of Erection.	Cylinder.		Pumps.		Water raised per stroke.	Depth of Well.	Total Height of Lift.	Actual Horse power used.	Boilers.				
			Diam.	Stroke.	Diam.	Stroke.					No.	Length.		Width.		Description.
			Ins.	Ft. Ins.	Ins.	Ft. Ins.	Galls.	Feet.	Feet.	H. P.		Ft.	Ins.	Ft. Ins.	Description.
Green Lane No. 1	Cornish	1846	50	9 0	17¼	8 9	83	185	275	70	3*c*	26 0		5 9	Cylindrical
„ No. 2	Do.	1852	52	9 0	19	8 8½	104	185	275	77	3*d*	26 0		5 9	Do.
„ No. 3	Double-act. crank condens.	1837*a*	34	6 1	17	4 0	39	185	275	52	2*d*	26 0		5 9	Do.
Windsor...........	Cornish	1840	50	9 0	16⅛	8 9	75	210	287	62	4	33 0		5 0	Do.
Bootle No. 1	Double-act. crank condens.	1821	34	6 0	16⅓	8 9	31	50	170	28	5*e*	25 0		6 8	Wagon
„ No. 2	Do. do. ...	1814	31	6 0	16½	8 9	31	50	170						
Audley Street ...	Cornish	1857	36	6 2	19	6 2	74	20*b*	100	...	2*f*	20 0		6 6	Cylindrical
Devonshire Place	Double-act. crank non-cond.	1838	14¼	6 0	15⅝	4 0	31	20*b*	106	17	2	20 0		5 0	Do.
Bush	Single-acting condensing ...	1801	38	6 0	11½	5 9	21	149	228	16	2	18 5 21 0		7 9 6 0	Wagon Horseshoe
Soho	Double-act. crank condens.	1825	30	6 0	9 10	8 11 4 9	34	123	247	27	2	21 7½ 22 0		7 0 6 9	Wagon
Hotham Street ...	Do. do. ...	1801	27	5 0	8⅝	3 4½	15	110	205	12	1	19 0		6 2½	Do.
Water Street	Do. do. ...	1827	30	6 0	12⅛	8 11	19	156	257	24	2	30 0 24 0		6 6 8 0	Cylind. *g* Wagon

a, transferred from Bootle 1855. *b*, these engines pump from reservoirs. *c*, 3 ft. 6 ins. fireboxes with four 13 ins. flues. *d*, 3 ft. 6 ins. fireboxes with three 14 ins. flues. *e*, these were all old boilers of which three only were worked at a time; they have now been removed and replaced by cylindrical boilers like those at Green Lane. *f*, 3 ft. 10 ins. fireboxes with three 14 ins. flues. *g*, with one 3 ft. 10 ins. flue.

TABLE II.

Liverpool Water Works.

Cost of Pumping at the several stations.

Pumping Stations.	Total Height of Lift.	Total Water pumped in year.	Cost of Coal.			Cost of Stores.			Establishment Wages.			Cost of Repairs.			Total Cost.			Total Cost per mill. gals. per 100 feet of lift.
			Total in year.	Per million gallons.	Per 1000 gals.	Total in year.	Per million gallons.	Per 1000 gals.	Total in year.	Per million gallons.	Per 1000 gals.	Total in year.	Per million gallons.	Per 1000 gals.	Total in year.	Per million gallons.	Per 1000 gals.	
	Ft.	Gallons.	£ s. d.	£ s. d.	d.	£ s. d.	s. d.	d.	£ s. d.	£ s. d.	d.	£ s. d.	s. d.	d.	£ s. d.	£ s. d.	d.	£ s. d.
Green Lane	275	1,065,161,241	1319 19 0	1 4 9	·297	219 19 1	4 2	·050	538 5 2	0 10 1	·121	405* 16 10	7 7	·091	2484 0 1	2 6 7	0·559	0 16 11
Windsor	287	374,310,750	452 8 2	1 4 2	·290	86 2 3	4 7	·055	278 4 2	0 14 10	·178	105 1 9	5 7	·067	921 16 4	2 9 2	0·590	0 17 2
Bootle	170	282,240,120	536 11 9	1 17 4	·448	92 1 1	6 6	·078	284 6 11	1 0 1	·241	78 2 11	5 2	·062	986 2 8	3 9 1	0·829	2 0 8
Audley Street and Devonshire Place	106	176,384,730	328 19 7	1 17 3	·447	23 1 10	2 7	·031	154 9 3	0 17 6	·210	40 11 2	4 6	·054	547 1 10	3 1 10	0·742	2 18 4
Bush	228	98,402,304	337 18 9	3 8 8	·824	25 17 2	5 3	·063	175 1 2	1 15 7	·427	30 12 5	6 2	·074	569 9 6	5 15 8	1·388	2 10 9
Soho	247	176,111,858	478 13 0	2 14 4	·652	58 8 9	6 7	·079	186 6 11	1 1 2	·254	115 17 11	13 1	·157	839 6 7	4 15 2	1·142	1 18 6
Hotham Street......	205	90,893,190	331 10 6	3 12 3	·867	31 5 10	6 10	·082	141 9 5	1 11 0	·372	47 8 6	10 4	·124	551 14 3	6 0 5	1·445	2 18 9
Water Street	257	156,426,075	407 6 9	2 12 0	·624	57 13 1	7 4	·088	190 1 10	1 4 4	·292	42 15 2	5 4	·064	697 16 10	4 9 0	1·068	1 14 8
Total or Average ...	...	2,419,930,268	4193 7 6	1 14 8	·416	594 9 1	4 11	·059	1948 4 10	0 16 1	·193	861 6 8	7 1	·085	7597 8 1	3 2 9	0·753	1 19 6

* The repairs at Green Lane during this particular year were heavier than usual.

TABLE III.

Liverpool Water Works.

Comparative Economic Value of different mixtures of Lancashire Coal and Slack.

Number of experiment.	Duration of experiment.	Fuel consumed.			Total Number of Strokes.	Load lifted per stroke.	Mean Height of Lift.	Weight lifted one foot high per cwt. of fuel.	Comparative Economic Value of Fuel.	Ashes.		Water evaporated.	
		Coal.	Slack.	Total.						Total weight.	Per cent. on fuel.	Total.	Per lb. of fuel.
No.	Hours.	Tons.	Tons.	Tons.	No.	Lbs.	Feet.	Lbs.		Lbs.	Per cent.	Gallons.	Lbs.
1	105	5·00	5·00	10·00	58,020	835	268·72	65,092,986	1·0000	1627	7·26	19,390	8·65
2	100	5·00	5·00	10·00	55,950	835	269·43	62,936,490	0·9668	1872	8·35	18,490	8·25
3	95	5·00	5·00	10·00	52,570	835	269·08	59,057,611	0·9072	1314	5·86	17,410	7·77
4	97	5·09	5·31	10·40	53,300	835	268·82	57,519,079	0·8836	2149	9·22	17,550	7·53
5	87	5·00	5·00	10·00	48,290	835	269·02	54,237,323	0·8332	1722	7·68	15,950	7·12
6	85	5·00	5·00	10·00	47,400	835	268·83	53,200,112	0·8173	1865	8·32	15,780	7·04
7	84	5·00	5·00	10·00	45,860	835	269·50	51,599,952	0·7927	1338	5·97	14,990	6·69
8	79	5·00	5·00	10·00	44,290	835	267·36	49,437,838	0·7595	857	3·82	14,640	6·53
9	80	5·10	5·05	10·15	44,770	835	267·23	49,211,062	0·7560	1910	8·40	14,780	6·50
10	79	5·00	5·00	10·00	43,620	835	269·42	49,065,019	0·7537	1675	7·47	14,510	6·48
11	81	5·15	5·17	10·32	44,420	835	269·20	48,852,622	0·7428	2006	8·67	14,890	6·44

The **Chairman** enquired in what way the gutta-percha beats were applied in the pump valves, and how long they were found to stand in work; also whether vulcanised india-rubber had been tried for the purpose.

Mr. **Duncan** replied that he had not tried vulcanised india-rubber for the valve beats. The gutta-percha beats were put in just the same as the ordinary gunmetal beats in double-beat valves, and they lasted about six months in constant work before requiring renewal.

Mr. J. **Ramsbottom** thought the bored and turned joints that had been described in the paper appeared a very good method of jointing the pipes of the mains, and much more economical than the ordinary lead joints. He enquired whether it was necessary to warm the ends of the pipes for making the joints, and whether the asphalt when cold was in a condition to admit of being set up with a caulking chisel in the ordinary manner.

Mr. **Duncan** replied that it was necessary to warm the sockets of the pipes in making the joints, in order to cause a slight expansion, so that the subsequent contraction in cooling might make the joint completely tight; and a single thread of tarred yarn lapped round the spigot end was found quite enough to afford the very small amount of elasticity needed in the joints. The asphalt was then run in, and no upsetting was required afterwards, as it was sufficiently liquid to fill every part of the space between the spigot and socket. He had tested joints made in this way up to a pressure of 200 lbs. per square inch without any leakage taking place. The pipes at present laid with the bored and turned joints had however been of much smaller dimensions than the large water works mains described in the paper, and the mode of warming the sockets for making the joints was by means of a coke fire in a cradle, over which the socket end of the pipe was suspended horizontally and turned round slowly till sufficiently warmed. For large pipes however, such as the 44 inch main, he proposed to heat an iron ring in a furnace and then slip it inside the socket for a few minutes to warm the socket.

The **Chairman** thought there would be no practical difficulty in applying that mode of jointing to large pipes if they did not get out of shape in warming the sockets. He asked what was the largest size of pipe that had yet been laid with the bored and turned joints.

Mr. **Duncan** replied that the largest pipes he had hitherto laid with the new joints were 11 inches diameter; some at Glasgow were being laid of 15 inches diameter, and some made for Melbourne were 30 inches diameter.

Mr. J. **Cunningham** enquired what was the inclination of the taper that was found to answer best in the bored and turned joints.

Mr. **Duncan** replied that the inclination was 1 in 62 to the axis of the pipe: a higher inclination had been tried but did not suit so well, as the joints then began to show leakage at the testing pressure.

Mr. W. **King** observed that the bored and turned joints had been used by his father for the gas pipes in Liverpool from 24 inches down to 3 inches diameter for the last thirty years, and they had proved thoroughly satisfactory. The inclination of the taper of the joints was 1 in 32 on each side, and experience had shown that for gas pipes this taper completely answered the purpose.

Mr. J. **Kennan** had heard that at the Dublin Water Works the joints of the pipes were made taper similarly to those now described, except that they were not bored and turned but put together rough. The mode of laying them was to lay two pipes with the tapered end of one in the socket of the other, and then a block of wood being placed across the outer end of the second pipe, a third pipe was swung against it endways, so as to drive the joint up tight between the two first pipes; afterwards the ordinary packing of tow was rammed in and the socket closed with lead.

Mr. C. **Markham** enquired whether the 24 inch pipes that had been deflected under pressure in the experiment described in the paper had the bored and turned joints put together without any lead.

Mr. **Duncan** replied that the joints experimented upon were made exactly in the manner he had described, without any lead, being merely bored and turned and put together with asphalt. The pipes at Dublin that had been referred to, with taper joints put together rough, were only overflow pipes for carrying off the surplus water from the reservoir, and the joints therefore were not required to be made good enough for standing a heavy pressure without leakage.

Mr. R. **Maclaren** stated that in the Rathmines Water Works, which conveyed the water into that new district of Dublin, the pipes were all laid with bored and turned joints, and he had recently been over 4 miles of the course of the mains where they were under a high pressure without finding a single sign of a leaky joint. The pipes of the old Dublin Water Works had the common lead joints, and it had been intended to lay these new pipes with lead joints; but the success of the bored and turned joints elsewhere and the economy in laying them led to their being adopted instead. The pressure of the water was from 350 to 400 feet head, but the joints were tested up to 600 feet head. He had also made the whole of the city pipes for the new Loch Katrine water supply in Glasgow, all of which had the bored and turned joints from 15 inches diameter downwards.

Mr. **Sampson Lloyd** asked what had been found to be the actual saving in cost with the new joints, including the boring and turning.

Mr. R. **Maclaren** replied that the cost of laying the pipes with the bored and turned joints was only half that of laying pipes with ordinary run lead joints, including the cost of boring and turning; the cost of laying alone being therefore less than half. The boring and turning cost from 5*s.* to 10*s.* for each ton of pipes, according to the length of joint and diameter of pipe.

Mr. J. **Mackay** observed that in the Edinburgh Water Works constructed in 1824 the junction and valve boxes had been laid with flanged joints, and he enquired whether these joints were ever used for water works stop valves at the present time.

Mr. **Duncan** said flanged joints were used before the modern spigot and socket joints, but no flanged joints were now used for water works pipes excepting in cases of special castings. The successful employment of the bored and turned joints for many years past in gas pipes, which had been mentioned, had led him to endeavour to extend the same plan to water pipes, as he was satisfied of the advantages of the new joints in simplicity and economy of laying: but it had been necessary to feel the way slowly and carefully in applying these joints to large pipes and under the far heavier pressures of water mains compared with gas mains. The results hitherto obtained however appeared to him so satisfactory as to warrant the general adoption of the bored and turned joints for water works purposes.

The **Chairman** enquired whether the self-acting shut-off valves that had been described in the paper, for shutting off the delivery of water from the reservoirs in the event of a breakage of the main, were found ever to get out of order and fail in their proper action.

Mr. **Duncan** replied the shut-off valves had never failed to act properly when an accident had occurred, closing at once the outlet from the reservoir. It had indeed sometimes happened that the valves had run down accidentally without any breakage of the main: but the only inconvenience resulting from this was the stoppage of the water until the valve was set open again.

Mr. H. C. **Beloe** enquired whether any efficient means had been found for preventing waste of water. In the Liverpool Water Works, notwithstanding the very large supply of water now possessed, the demand was increasing so rapidly with the increase of population as to give cause for some anxiety about the continuance of the supply, and the want of some efficient means for preventing waste was much felt. At Whitehaven, where the works were similar to those of Liverpool, the supply being derived from a lake in the immediate neighbourhood, it had been necessary to issue an appeal to the inhabitants not to waste the water, that the supply might not run short.

Mr. I. **Smith** observed that the waste of water had become a very serious subject in some towns where the system of constant supply was maintained. In Birmingham the waste was very extensive, and a house to house visitation had been made to ascertain the cause; and he understood that if the waste could be prevented the water would be supplied at one half to one third of its present cost. He thought an important step towards preventing waste would be the adoption of water meters by all manufacturers using a large quantity of water, and wherever steam boilers were employed the use of a meter would also have the advantage of showing the amount of water evaporated in comparison with the fuel consumed, which would lead to greater economy than at present prevailed. He was himself about to put down some water meters in Birmingham, and he enquired what meters were found good and reliable for regular working.

Mr. **Duncan** said he had constructed meters himself, which he had now had at work for five years, and though somewhat expensive they always indicated within one per cent. on either side of the actual quantity, when treated with moderate care. He had tried the single cylinder meters with tumbling lever for reversing the valve, and had found the constant knocking was apt to end in a breakage, and if the tumbler ever stopped on the centre it allowed the water to flow through the meter without being indicated. This he considered a radical defect in any construction of meter, and his object had therefore been to obtain one that was sufficiently simple in construction and could not be tampered with and would continue in efficient working order for a considerable number of years, registering correctly the quantity of water passing through, without being liable to any derangement. The meters he had constructed had a pair of measuring cylinders with pistons and rods and slide valves, the pair being coupled together by a shaft with cranks at right angles, so that it was impossible for either piston to stick on the centres; and the piston rods were connected to the crank pins by slotted crossheads, having slightly curved slots allowing one cylinder to follow the other in action, with a smooth continuous flow of the water through the meter. A worm on the crank shaft worked the registering dial by means of gearing in the ordinary manner.

Mr. P. P. **Marshall** remarked that in the water works of the North London district, in order to prevent waste of the water, the service pipes had originally been fitted with "preventors," consisting of a long vertical cast iron cylinder containing a weighted gutta-percha ball of 3 inches diameter, the cylinder being made slightly larger in diameter, with the supply pipe entering at the bottom and the discharge pipe passing off from the top. When the tap was turned to draw off water, the rush of the water into the cylinder carried the ball with it and closed the orifice of the discharge pipe, so that only one cylinder full of water could be drawn off at a time; and when the tap was closed, the ball sank again gradually by its own weight to the bottom of the cylinder. These preventors however had now all been removed, as they were found inconvenient in use and did not affect the waste of water sensibly: for the great cause of waste was in the constant supply system, when taps were liable to be left partly open, and here the preventor did not act, as a slight flow of water was not sufficient to raise the ball effectually, and then the water could run to waste. The parliamentary average for water supply was reckoned at from 5 to 25 gallons per day to each inhabitant, but in the North London district he was supplying from 60 to 70 and even 100 gallons per head per day. The best plan for preventing waste he thought would be to compel each house to have a cistern for the water, and to fill the cistern only once a day.

Mr. I. Smith hoped the use of cisterns would not be reverted to, for the report of the sanitary commission showed that where houses were supplied by cisterns a great deal more illness prevailed, especially among the poor, who would not keep the cisterns clean and covered over, and a quantity of foul matter gradually accumulated in them in consequence. Moreover cisterns were not really productive of much saving of waste he thought; for he had observed that in Walworth, London, when the supply of water was turned on, the practice was to take out the plug of the cistern and allow the water to run to waste until near the time of the supply being stopped, in order to cleanse the cistern with little trouble.

Mr. P. P. Marshall observed that outside cisterns might be arranged to be cleaned regularly by the local authorities supplying the water, without any trouble to the consumers; but in the case of internal cisterns that were covered over, he had found the necessity for cleaning scarcely ever arose where the water was pure. In reference to the poorer classes and small properties, the neglect was generally on the landlord's part, and he had known of some cases of houses being altogether deprived of water for many weeks through the landlord's neglect.

Mr. J. Mc F. Gray suggested that ordinary water taps might be made with a spring added, so as to keep them always shut, in order to prevent waste; and he had seen taps made with a sliding piston or plug, closed by a spring, which only ran so long as the plug was kept pressed down by the finger.

Mr. I. Smith said the objection to that sort of valve was that with a high pressure of water the sudden closing of the valve caused too great a shock and damaged the pipes, by suddenly stopping the current of water. The india-rubber diaphragm valves closed by a screw were much superior in this respect, the diaphragm being made of cloth between two layers of india-rubber, so as to stand the screwing pressure; and the only objection he had found to them was that in careless hands they were apt to be screwed down too tight in shutting off the water, so that the india-rubber diaphragm was cut through, and had to be replaced.

Mr. J. J. **Birckel** enquired whether the sand washing apparatus at the filtering works continued to work efficiently, and what was the quantity of sand it would wash in regular work. He understood the original machine at Crewe, on the principle of which the present one was constructed, had proved very satisfactory in working.

Mr. **Duncan** replied that the sand washing machine had been found thoroughly satisfactory, washing 10 cubic yards of sand per hour and loading it into wagons ready for use.

The **Chairman** remarked that the Liverpool Water Works were amongst the finest at present in existence; and in consequence of their twofold character, partly gravitation and partly pumping, there was ample scope for future extension to meet the increasing requirements of so large a commercial town. He moved a vote of thanks to Mr. Duncan for his paper, which was passed.

The Meeting was then adjourned to the following day. In the afternoon the Members were conveyed by special steamer, granted for the occasion by the Cunard Steam Ship Co. through the kindness of Mr. MacIver, to the Mersey Steel and Iron Works, which were opened to their inspection: they were also handsomely entertained at the works by Mr. Clay. In returning, the steamer was taken round the Great Eastern steam ship lying in the river.

The Adjourned Meeting of the Members was held in the Concert Room, St. George's Hall, Liverpool, on Wednesday, 5th August, 1863; William Clay, Esq., Chairman of the Local Committee, in the Chair.

The following paper, communicated through Mr. George Harrison, was read:—

ON THE MECHANICAL VENTILATION AND WARMING OF ST. GEORGE'S HALL, LIVERPOOL.

BY MR. WILLIAM MACKENZIE, OF LIVERPOOL.

The works for Ventilating and Warming St. George's Hall, Liverpool, are from the plans of the late Dr. D. B. Reid, and may be classed under the five following heads:—Supply of Air, Warming, Cooling, Moisture, and Ventilation. The arrangements for these several purposes are shown in the diagrams, Plates 54, 55, and 56. Fig. 1, Plate 54, is a longitudinal section from end to end through the centre of the building. Figs. 2 and 3, Plate 55, are plans showing the arrangement of the air passages in the basement of the building, at the levels of the upper and the lower air channels respectively. Fig. 4, Plate 56, is a transverse section through the civil court, looking south. In all these diagrams the course of the air is indicated by the arrows, and the vitiated air is shown by the dotted portion.

Supply of Air.—The principal supply of air is by the two descending shafts A A, Figs. 3 and 4, Plates 55 and 56, at each end of the east portico. These are connected together by a long passage, from which there are lateral arches leading to the four ventilating fans B B that send the air through the building. On account of the graveyard on the west side of the building, air is not admitted on that side, except by windows and when the barometer is high. There are also supply shafts to each court, and openings along the sides of the central hall immediately above the windows, Fig. 1, Plate 54, by which air is brought down to the galleries of the hall, so that when necessary a very large additional supply of air can be obtained from the highest part of the building; but in general the supply from the shafts A A alone is preferred, and with few exceptions has been found sufficient.

Warming.—The air is warmed by means of two steam boilers C D, Fig. 3, Plate 55, and two hot water boilers E F; to which are attached 32 coils of pipes, 5 for hot water, shown at G H I J K, and 27 for steam, of which 3 are shown at L M N. The pipes forming the hot water coils are 4 inches diameter, and those forming the steam coils 2 inches diameter; the supply pipe from the hot water boilers is 12 inches diameter, and that from the steam boilers is the same as the coils, 2 inches diameter. On the top of the hot water boilers expansion boxes are placed to receive the increased bulk of the heated water; and on the leading and other pipes there are expansion joints and stop valves, so as to keep the joints of the pipes in proper order. Thermometers are placed in front of the hot water boilers E F, as well as on the main coils H I, so that the difference in temperature between the flow and return pipes is easily ascertained. The average heat in the hot water boilers is 150° Fahr., the return water being from 15° to 20° cooler. In connexion with the coils there is an arrangement of air valves in the chambers, which effectually shuts off the heat when a reduction of temperature is required, so as to avoid running off the hot water from the boilers. The water in the boilers and pipes is changed as seldom as possible, so as to prevent corrosion in them. The hot water apparatus is the important source of heat for the principal parts of the building, and is the one always used, except in extreme cold weather; since the less the temperature is elevated, the more agreeable is the quality of the air.

The five hot water coils are arranged in the situations shown in the plan, Fig. 3, Plate 55, and are as follow:—

1. The main south coil H
2. The main north coil I
3. The south hall coil G
4. The west concert coil J
5. The east concert coil K

The heat from the whole of the coils can be directed on any given apartment or subdivided as occasion requires by opening or closing the numerous valves or doors in the air chambers that extend over the whole building, in a manner very similar to the mode of regulating the ventilation in a coal mine. In simply warming the building, all the valves for the escape of vitiated air are closed, and the same air is driven by the fans round and round the hall, courts, and corridors, until the required temperature has been reached. By thus preventing the escape of warm air before it is contaminated, a considerable saving is effected in the consumption of fuel. The building is kept at a temperature as near 65° as possible. The fuel used for the boilers is soft coke, but ordinary gas coke is used for the open fireplaces, the great height of the smoke shafts causing a very powerful draught.

The steam apparatus, of which three coils are shown at L M N, Fig. 3, Plate 55, is used principally as an auxiliary warming power, and in the winter months the steam coils are used in the early part of the morning before the commencement of business, to warm the halls and passages; and the heat is afterwards maintained by the hot water coils, depending of course upon the state of the external atmosphere, the quantity of air required, and the manner in which the water apparatus may at the time be in use. All the coils have their appropriate stop valves, and can be put in operation either collectively or individually. In very cold weather, or when heat is suddenly or quickly required, then by an arrangement of steam pipes the steam itself is blown into the warm air passages, care being taken that no more is given than the atmosphere will absorb.

Cooling.—In the summer the various hot water coils are used for cooling the air, cold water being introduced into them instead of hot, and caused to run through them to such an extent as may be necessary. The vaults however are always so cool that this process is seldom resorted to.

Moisture.—In artificial warming, moisture is of the greatest importance, for if the air is warmed to a summer heat it ought also to possess the summer moisture. A special steam boiler O, Fig. 3, Plate 55, is employed for this purpose, to which pipes are attached so as to convey the steam to each of the principal warming apparatus where moisture is most likely to be required; the steam is there discharged into the air, the quantity being regulated by a hygrometer. To prevent the steam from imparting any objectionable effluvium to the air, the boiler is made of copper and the pipes of block tin 2 inches diameter.

In addition to this steam boiler there is a fountain P in the entrance air shafts A A, Figs. 3 and 4, Plates 55 and 56, so that before the air is allowed to enter the cold air chambers it must pass through a spray of water varying from a gentle shower to a saturating mist, not so much for the purpose of receiving moisture, but in order that it may be washed and thereby caused to enter the building free from smuts and dust. Were it not for this provision, the smell of soot from a neighbouring chimney on fire or any other offensive smell would at once be drawn into the fans and wafted throughout the building.

Ventilation.—The ventilating arrangements have been made so as to secure from 7 to 10 cubic feet of air per minute to each person occupying the building, and the extent of opening of the supply valves is therefore regulated by the number of persons present, the quantity of air driven through the building varying from 1,000 to 50,000 cubic feet per minute. The openings for the diffusion of the air into the several compartments of the building are as numerous as its structural arrangements will allow, and they are controlled in such a way that the whole or only a portion of them can be open at one time.

Exactly under the middle of the floor of the central hall a 10 horse steam engine is fixed at R, Figs. 1 and 3, Plates 54 and 55, for the purpose of driving the four fans B B, which are 10 feet diameter and 5 feet broad, the blades being 2½ feet in width; they are driven at a speed of from 45 to 60 revolutions per minute. The engine is horizontal, and the fans are placed one on each of its sides, and are known from their position as the north, south, east, and west fans. The space between the floor of the hall and the engine room is divided into three channels S, Fig. 4, Plate 56, called respectively the cold, warm, and temperate air channels. Each fan has its own section, and the four fans may thus be working simultaneously on different portions of the building, distributing air at various temperatures according to the occupation of the different apartments. When necessary however all the four fans can easily be concentrated and made to supply air to any one section of the building. Thus the air may be driven through the main north coil I, and after being warmed thereby may be conveyed to the civil court and the concert room, Fig. 1; whilst the main south hot water apparatus H may be shut off, so that cold air is supplied to the central hall and the crown court. These arrangements can be readily interchanged in any manner desirable, by simply altering the arrangement of the valves in the air passages.

In an edifice like this, where the requirements are so varied, it is most important that ample mechanical power should be available so as to meet the sudden changes that frequently arise, as for instance when the building is wholly or partially occupied. Special care has therefore been taken to have sufficient power to meet every change of circumstance, such as a sudden increase or decrease of numbers occupying any of the large apartments, either case requiring a corresponding alteration to be made in the working of the ventilation, and at the same time to be effected without causing discomfort. At a concert in the large central hall, Fig. 1, Plate 54, it often happens that one part of the room may be crowded to excess, whereas in another part it may be nearly empty; and this is more particularly illustrated when seats are reserved for a portion of the audience in evening dress, and the other parts of the room are filled by persons in ordinary dress. It is obvious that the same temperature will not be agreeable to both, and consequently arrangements are made by which those in the reserved seats are kept in a temperature considerably warmer than would be pleasant to those in the body of the hall. In many cases more depends upon the rapidity of circulation of the air than upon its actual temperature, which may be the same for all parts of the hall, or if necessary varied. This also applies to the crown court and civil court, which are divided into zones, giving a separate supply to the judge, bar, and general public, one part of the court being much more crowded than another. The temperature of the principal apartments is recorded every hour, and for this purpose a number of thermometers are placed in different parts of the central hall, courts, and concert room. The rapidity of circulation causes a difference between the apparent and actual temperature, the latter being higher than is imagined by those exposed to it; and consequently the thermometers are locked up and concealed from ordinary observation, because under certain circumstances it is better to increase the velocity of the air at a high temperature and thus make it feel cooler, than to reduce the temperature by supplying cold air and thereby causing discomfort to those who happen to be near to the openings for supply.

A person may feel very warm whilst walking during a hot summer day; but in riding on a vehicle driven at an ordinary speed, the air without change of temperature becomes agreeably cool. By the aid therefore of the engine and fans, complete control is exercised over the quantity of air supplied, giving at the same time the effect of a plenum of pressure, which can alone entirely neutralise draughts and currents at doors in crowded apartments.

The vitiated air is discharged at the ceilings of all the apartments, as shown by the dotted portions in the diagrams, Figs. 1 and 4, Plates 54 and 56; and after passing through channels between the ceilings and roofs is discharged into the external atmosphere by the four shafts T, Fig. 4, forming the angles of the central hall. Every panel or opening in the ceilings is controlled by a valve, and the number that may at any time be open depends upon the quantity of fresh air supplied from below, the supply regulating the discharge. With the exception of the central hall, the whole of the vitiated air from the concert room, courts, rooms, and cells is drawn towards the four shafts T; and in order that this may be done as effectually as possible, provision is made for coke fires and large jets of gas to be used as occasion may require, for rarefying the air in these shafts and thereby drawing off the vitiated air more rapidly. The draught of the shafts is controlled by iron doors, and can be regulated to suit the various movements to which the ventilation of the building is adapted. Owing to the great height of the central hall, the four shafts T are not available for this portion of the building; and the vitiated air from it is therefore discharged through the ceiling of the hall into a large foul air chamber formed between the ceiling and roof, and afterwards into the open air through glass louvres U, Fig. 1, which extend all around the highest part of the roof. These louvres are controlled by valves, so that any side may be used for the discharge of the vitiated air, according to the direction of the wind.

In order that the force or velocity of the air circulating through the building may be readily tested, with regard to either supply or discharge, small anemometers are placed at all the supply and discharge valves. These are simply paper cylinders, about 1 inch long and ¼ inch diameter, suspended permanently in a vertical position by silk threads; and from the angle at which they are inclined by the current of air, the strength of the current is observed. By this means it is easy to perceive from the floor of the central hall whether the discharge valves in the ceiling are open or shut; and thus a check is always kept on the men whose duty it is to carry out the ventilation.

The various chimneys of the building are collected into the four shafts T, Fig. 4, Plate 56; but before reaching them the smoke from the individual fireplaces in the various rooms is collected into horizontal flues of large area, passing beneath the roofs, lower than the highest portions of the building, and afterwards ascending by the vertical shafts T. These four great shafts are each divided into three compartments, two being for the smoke and one for the vitiated air, each of the four large boilers C D E F, Fig. 8, Plate 55, having a special flue to itself. On the top of these shafts but not reaching above the height of the parapet wall, iron louvres are fixed, made of angle iron and thin sheet iron, and constructed so as to allow the vitiated air and smoke to escape as well as to prevent the rain from descending. Surrounding these louvres deflectors are placed for the purpose of breaking the force of the wind, thereby causing an eddy, and thus preventing a down draught. Dr. Reid considered that in introducing these shafts he had effected a great saving in the architectural expense, besides maintaining more strictly the style of architecture adopted. These four shafts have prevented the introduction of ornamental chimneys, and have saved the building from the unsightly incongruities too frequently seen on the chimney tops of public buildings for the purpose of preventing a down draught.

The air valves in the warm air chambers are light wood frames, covered with canvas and strong paper, and afterwards painted so as to allow of washing. The walls of the warm air chambers, instead of being plastered in the usual manner, are covered with cinders and plaster from 2 to 3 inches in thickness, so as to enable them to retain the heat when once they are warmed; and by this means a considerable saving is effected in the production of heat on subsequent occasions. The position of the boilers C D E F, Fig. 8, Plate 55, underneath the floor of the central hall, Fig. 1, might probably cause some fear as regards explosion; but the working pressure is so far below what the boilers can sustain, and so regulated by gauges in connexion with the manager's office by means of magnetic wires to an alarum, as well as by steam gauges fixed on the office wall, that the fixed limit of pressure cannot be exceeded without immediate discovery.

In conclusion it may be stated that the building is an immense pneumatic machine, kept in operation according to the necessities of its occupation. When the building is unoccupied, the air courses through the warm and cold air chambers, the halls, courts, and corridors, to the extremities of the building; whence it returns to its central source to be again dispersed. But with the building in occupation, the order is different: the air then becomes contaminated and is discharged, and the supply and discharge are proportioned to the extent of contamination. It is easy to admit air or remove it from any part of the building, or to reduce the action: but the amount of satisfaction finally depends on the skill and delicacy with which the movement, temperature, moisture, and quantity of the air are adjusted, so as to suit the feelings of the audiences during the various seasons of the year. To do this effectually, care has to be taken as far as possible to anticipate every change that fluctuating circumstances may render desirable; but at the same time not to yield too easily to the mere importunities of any persons of delicate constitutions, who are usually the first to demand and the last who should guide any change that may be in opposition to the general feelings of those who are present.

The CHAIRMAN enquired what was the limit of pressure of the steam in the boilers employed for driving the engine and for warming, and what construction of boilers was used.

Mr. MACKENZIE replied that the boilers were all ordinary Cornish boilers, cylindrical with a single flue through them. The steam pressure was limited to 30 lbs. per square inch above the atmosphere;

and by the system of safety apparatus that was adopted as described in the paper, and the electric indicator communicating with his own office, a complete check was provided against any risk of this pressure being exceeded in work.

Mr. F. J. **Bramwell** observed that he had had an opportunity of inspecting the arrangements described in the paper for the ventilation and warming of St. George's Hall, which appeared to him to be very perfectly effected. With reference to the mode of cooling the air in hot weather by filling the ordinary hot water apparatus with cold water, he enquired how the water was obtained cold enough for that purpose, as the water might be expected to be near the same temperature as the external atmosphere, in which condition it would not be of use for cooling the air. He asked also what proportion of moisture in the air had been found by experience to be most desirable at the different temperatures, and whether the dry and wet bulb thermometer was used for ascertaining the degree of humidity; it was a delicate matter in ventilation to adjust the moisture in the air to the point at which the air could be breathed with comfort. He fully concurred in the necessity of washing the air to cleanse it from impurities, having had opportunities of observing the great amount of impurities with which the air was charged in large towns. In the case of a large corn mill in London running 32 pairs of stones, where he had put up four fans of 3 feet diameter for supplying the stones with air to facilitate the process of grinding the grain, the fine flour dust which remained suspended in the air and was collected for use had been found to be so blackened by the impurities mixed with it by the air as to be unfit for any except the commonest purposes, such as making paste for bill posting and other analogous purposes. As the air driven through the stones was required to be as dry as possible, in order to assist in taking moisture from the flour, the air could not be cleansed in this instance by washing: and he had therefore put up a number of fine dry canvas screens, one behind another, for the air to be strained through on its way to the fans, and it was astonishing to find the quantity of dirt that accumulated on these screens in a short time, showing the great extent to which the air of London was contaminated with impurities.

Mr. Mackenzie said the temperature of the water used for cooling the air in hot weather was generally about 54° or 55° Fahr. as supplied direct from the water works mains, when the air itself was at about 60° or even higher, so that there was sufficient difference of temperature to allow of the air being considerably cooled by the circulation of the water through the pipes. For ascertaining the degree of moisture in the air, wet and dry bulb thermometers were constantly employed in the air passages, and by adjusting the moistening apparatus a difference of 4° was regularly maintained between the two bulbs, which was found to give just the proportion of moisture that was pleasant for breathing. In reference to cleansing the air by washing it previous to its dispersion into the building, the effect of the cleansing had been found to be a saving of about 24 shillings a week in the cost of cleaning the air passages, valves, and pipes, two persons being now dispensed with that were previously required for that purpose.

Mr. F. J. Bramwell remarked that Liverpool was fortunate in having a supply of water from the water works at as low a temperature as 54° in hot weather: in London it was rare to find the water from the mains nearly so cool as that during the summer. In the two steam boilers that were used for heating the numerous steam coils he enquired whether the water was returned to the boilers after condensation, or whether fresh water was supplied to the boilers.

Mr. Mackenzie replied that the water from the steam coils was not returned to the boilers, but fresh water was put in. It was only in the hot water pipes and the two hot water boilers that the same water was used over and over again, because in that case the temperature of the water was always below the boiling point, amounting to only about 150°, so that no steam was generated and none of the water evaporated; but these boilers also were discharged at regular intervals and refilled with a fresh supply, while the pipes themselves were not emptied except on rare occasions.

Mr. T. W. Plum thought the plan of admitting the fresh air at the bottom of the apartments to be ventilated and taking off the foul air at the top was contrary to the principles of natural ventilation;

and suggested that the better way would be to admit the fresh air at the top and remove the vitiated air below, especially in churches and other large public buildings. By this means a constant supply of fresh air would be imperceptibly provided for breathing, instead of being first partly contaminated by entering at the feet and passing up over the surface of the body.

Mr. **Mackenzie** observed that the objection to admitting the fresh air above and drawing off the foul air below was that by that plan the descending fresh air would draw down with it the products of combustion from the gas chandeliers, which in the present system were carried off with the products of respiration at the top of the room. In the concert room in which they were now meeting, the fresh air was admitted at each of the risers of the steps running all round the wall of the room at the bottom, Fig. 1, Plate 54; and also through the panels round the wall of the gallery, each panel being perforated and controlled by a valve: and the foul air from respiration together with the products of combustion from the chandeliers was all taken off through the perforated panels in the ceiling. In the central hall there were three modes of admitting the fresh air,—1st at the level of the floor, 2nd through panels in the walls a few feet above the floor, and 3rd through openings in the galleries and above the large windows; all of these could be employed at once if necessary, whereby an abundant supply of fresh air was provided, even when the hall was fully occupied: and the foul air all passed off through the apertures in the ceiling.

Mr. W. E. **Newton** concurred in thinking the better plan for ventilation was to bring the fresh air down from above, but in that arrangement the system of lighting would have to be altered, so as to keep the heat and fumes of the gas burners separated from the fresh air entering the room; and there were several plans of lighting by which that might be readily accomplished. The first object he considered was to find out by experiment the best mode of ventilation, without regard to its expense; and when that was ascertained, no doubt means would be discovered of reducing the expense to a minimum. Under the system of ventilation described in the paper as carried out in St. George's Hall, the consequence of bringing in the fresh air at the bottom of the rooms was that it became contaminated immediately on its entrance, through being breathed by the persons on the floor; and the whole room was therefore completely full of vitiated air. But if the air were admitted above and taken off below, and the lighting arrangements kept separate, it would not become contaminated until reaching the bottom, and the whole room would be full of pure air excepting only a thin stratum of vitiated air just at the floor level.

Mr. J. **Fernie** thought it was not the correct plan to admit the fresh air from above in large buildings, because the great difficulty in all such cases was to prevent down draughts. With the ordinary system of lighting from above, the gas burners near the ceiling necessarily produced a powerful ascending current, which was all available as an aid for ventilation when the fresh air was admitted below; but the whole advantage of this upward draught would be lost if the air were brought in at the top. He therefore thought Dr. Reid's mode of ventilation as here carried out was the correct plan.

Mr. I. **Smith** understood that the plan of admitting fresh warm air at the top and taking it away at the bottom by mechanical means, which was known as Van Hecke's method of ventilation, had been carried out at Baron Rothschild's new house in London; and the result was that so long as the rooms were not much occupied the ventilation was not bad, the vitiated air being then so greatly diluted by the large quantity of fresh air admitted; but when they were crowded and the gas lighted the air was not so good, owing to the hot impure air from the lungs and the highly heated products of combustion from the gas lights first rising to the upper part of the room. This effect might indeed have been anticipated, when it was remembered that in all ordinary buildings the air exhaled in breathing was at a considerably higher temperature than the atmosphere, being given off from the lungs at about 100° Fahr.; so that it would naturally rise, and could not be made to pass away with sufficient rapidity when taken off at the bottom of the building alone, while at the same time the fresh air descending from above became partly contaminated before it was used, by mixing with the rising vitiated air. In order to remedy the defect, a small portion of the impure air was taken off from the top of the room, and the remainder from the bottom.

Under particular circumstances no doubt it was right to admit the fresh air at the top, as in the case of Turkish baths, because there the temperature of the room was maintained at 120° to 140°, or 20° to 40° above that of the body, so that the air became in that case cooled instead of heated by respiration, and would therefore naturally pass off from the bottom of the room. But for ordinary public buildings he thought the system of ventilation carried out in St. George's Hall was the most perfect he had ever seen, the whole of the products of respiration and combustion being removed above and thereby prevented from tainting the pure air admitted below. The plan of forcing in the fresh air by mechanical means, by the four ventilating fans, had an important bearing on the success of the system, ensuring a constant plenum of pressure throughout the building, slightly in excess of the atmospheric pressure; in consequence of which it was impossible for any inward draught of cold air to take place when any of the doors were opened. Without resorting to such mechanical methods it appeared impracticable to ventilate large buildings satisfactorily; and he might mention that in the case of the Birmingham Town Hall the ventilation had hitherto been a complete failure, the only ventilating power being three large sunlights near the ceiling, which produced a strong upward current from the hall, but entailed also violent draughts through the doors whenever they were opened, and down draughts of cold air from the cooling surface of the windows when all the doors were closed: whereas if a supply of warm air were always brought in at the bottom the liability to down draughts would be obviated.

For the ventilation of dwelling houses or moderate sized workshops he had found mechanical appliances were not required; but the ventilation was efficiently accomplished by means of the simple ventilators on Mr. Muir's plan, which he had found invariably proved completely satisfactory, consisting of a vertical shaft or flue terminating at the top with open louvre sides and divided into four parts by two vertical partitions placed at right angles to each other: by this arrangement, in whatever direction the outer air might be moving or however slowly, the fresh air was made to pass down through two of the divisions into the apartment to be ventilated, while the vitiated air ascended through the other two divisions of the shaft. For house ventilation the air was thus brought down from the roof, which was a point of great importance in towns, where the air was more impure at the level of the ground. The size of the chimney flues also required considerable alteration from the present practice, as he had found that the ordinary chimneys were built far too large in proportion to the rooms and the fires burnt, causing an incessant draught from the doors or windows; and for houses of two stories high flues 9 inches square or even smaller were amply sufficient for the lower rooms. A throttle valve or damper should be inserted in the flue above the fire, as recommended by Dr. Arnott, for regulating the amount of the draught according to the size of the fire or the rapidity with which it was wanted to burn: and the firegrates should be made entirely of firebrick, without any iron about them excepting the bars in front. He had himself carried out these plans at his own house, having had the chimneys bricked up to 9 inches square, with throttle valves inserted and firebrick grates; and the result had been that for the last five years, ever since the alteration had been made, he had never required the chimneys sweeping, as there was never any soot deposited in them.

The amount of impurities contained in the atmosphere in large towns was certainly astonishing; for on taking down a ventilator cap at the works he was connected with in Birmingham, after it had been up about five years, he had found the inside of the ventilator was coated with soot, and the inside trough 3 inches deep surrounding it was completely filled with soot and dust; whilst a ventilator which had been up the same length of time four miles out of the town was still free from any deposit of the kind. This showed that it was highly desirable for the air to be purified in large towns, by some process of washing such as had been described; and the purification was even more important for private houses than in ventilating public buildings.

Mr. J. **Fernie** enquired how long the system of ventilation in St. George's Hall had been in operation: and in what respect it differed from that of the House of Commons, where he understood Dr. Reid's plans had been adopted.

Mr. **Mackenzie** replied that the St. George's Hall was opened in 1854, and the system of ventilation now described had been constantly at work with complete success from that time. This was the largest work that Dr. Reid had carried out, and the most successful, as in this building his own plans were thoroughly carried out, whereas at the House of Commons that was not the case: St. George's Hall was indeed the only large building where his system of ventilation had been carried out in its integrity according to his own views. The principle of the system was to assist the natural ventilation, instead of running counter to it; and the whole of the ventilating apparatus had proved entirely successful in working, without occasioning any difficulty at any time, and with no repairs or expenses beyond the ordinary working expenses of the engine and boilers.

The CHAIRMAN observed that the question of ventilation was one of great importance in all buildings, and more especially so in reference to public buildings in large towns. In the case of St. George's Hall he believed the ventilation was more efficiently accomplished than in any other large public building that he knew of, this being the only building in which Dr. Reid was supported by the architect and had his own plans thoroughly carried out. He moved a vote of thanks to Mr. Mackenzie for his paper, which was passed.

The following paper, communicated through Mr. John Ramsbottom, was then read :—

ON MACHINERY FOR THE MANUFACTURE OF PLATE GLASS.

BY MR. GEORGE H. DAGLISH, OF ST. HELEN'S.

Within the last ten years the production of Plate Glass in England has been quadrupled, whilst in the same time the price has been diminished fully one half. The present extent of the manufacture in this country is about 85,000 square feet per week, whilst about 12,000 square feet per week of foreign plate glass is imported. The foreign glass has obtained a preference from its superior lightness of colour, which arises from the greater purity of the materials that it is made of, particularly with regard to the sand, of which the foreign makers have an abundant supply, of great purity and light colour, as seen from the specimens now exhibited of English and foreign sand.

Under the influence of competition, the English manufacturers have lately commenced an extensive course of experiments with the view of improving the quality of the plate glass made in this country, and also reducing the cost of manufacture; and in some instances very decided success has thus far been the result. In order to accomplish these objects, the sand employed at the British Plate Glass Works at Ravenhead near St. Helen's is now imported from France; and every precaution is adopted to ensure as far as possible the chemical purity of the other ingredients of the glass. At these works also two of Mr. Siemens' regenerative gas furnaces (see Proceedings Inst. M. E., 1862, page 21) have been erected for melting the materials for the plate glass; and from the absence of smoke and dust in them, and the facilities they afford for regulating the heat, these furnaces have contributed greatly to the desired results. Under these altered circumstances the glass now manufactured is fully equal in every respect to the best samples of the French production.

As time is money, any improvement which tends to expedite the manufacture of glass is of importance. This is strongly exemplified in the process of annealing. After the materials have undergone the process of melting in the furnace and are considered in a fit state for casting, the pot containing the melted mass is taken to the casting table, and its contents poured out on one end of the table, in front of a large cast iron roller; the material is then spread out over the surface of the table by passing the roller over it, the thickness of the plate of glass being regulated by strips of iron placed along each side of the table, on which the ends of the roller run. As soon as the plate of glass is sufficiently solidified to bear removal, it is introduced into an annealing oven, there to be gradually reduced in temperature or "annealed," until it is fit to be exposed to the atmosphere without risk of fracture. This process of annealing used formerly to occupy upwards of a fortnight, but from the improved arrangement and construction of the annealing oven it is now completed in four days; thus three times the quantity of glass can now be annealed in each oven compared with what was formerly considered possible; and consequently a large outlay in building and in space has been saved, since only one layer of plates can be placed in the oven at one time, no method of piling the plates being considered practicable or even safe. The chemical difficulties and manipulation in producing the raw material have thus been very satisfactorily overcome; but the problem of carrying out the necessary improvements in the subsequent mechanical operations has not perhaps been so completely solved, though considerable strides have been made in that direction also.

The plates of glass when taken from the annealing ovens are exceedingly irregular, particularly on the surface which has been uppermost in the process of casting, that surface being undulated or wavy after the passage of the roller over it whilst in a semifluid state; the lower side too is affected by any irregularities on the surface of the casting table, and also to some extent by the floor of the annealing oven; and both sides of the plates are also covered with a hard skin, semi-opaque. The plates vary in size, the largest being about 17 feet long by 9½ feet wide; and the thickness varies according to the size from 3-8ths to 5-8ths inch. The first process to which the plates are submitted is that of grinding, to take off the hard skin and reduce the surface to a uniform plane, which is performed by the application of sand and water. The second process is that of smoothing, which is a continuation of the first process, but performed with emery of seven different degrees of fineness, so as to prepare the surface of the glass for the final process of polishing. This last process is effected by the use of oxide of iron employed in a moist state.

The machine in general use for Grinding is that which was originally employed at the commencement of the glass manufacture, and is believed to have been designed by James Watt. It is known by the name of the "fly frame" machine, and is shown in side elevation and plan in Figs. 1 and 2, Plates 57 and 58. It consists of two benches of stone A A, sufficiently large to hold a plate of glass, and placed about 12 feet apart; on these benches the plates of glass are fixed by plaster of paris, as shown by the black line in Fig. 1. Each bench has a runner frame B made of wood, about 8 feet long by 4½ feet wide, shod on the underside with plates of iron about 4 inches broad and ¼ inch thick, and provided with a strong wrought iron stud on the upper side, by which it is moved about over the surface of the glass. The gearing for driving these two runner frames B is placed between the two benches, and consists of the square cast iron fly frame C, with two flat bars D hinged to it on opposite sides, extending over each bench A, and suspended from the roof by long chains, as shown by the dotted lines in Fig. 1, so as to allow them to radiate freely in every direction; this is called the "fly frame" from the peculiar motion given to it, and each of the runner frames is connected to it by the central stud B, Fig. 1, working loosely in the slot between the bars D. The fly frame receives its motion from an upright spindle E, which is driven from the main line of shafting by a pair of bevil wheels with a friction clutch for throwing in and out of gear. On the top of the spindle E is a wrought iron arm or crank carrying a moveable stud, which works in a bush in the centre of the fly frame C. Round the centre spindle E are also four other spindles F, equidistant from the centre spindle and from one another, each carrying on the top a wrought iron arm or crank with moveable stud similar to the centre one; these studs severally work in bushes at each corner of the fly frame. Hence when motion is given to the centre spindle E, the fly frame C is carried round by the stud on the crank arm, while its sides are always kept parallel to their original position by the four corner cranks F. The two runner frames B, being connected by their central stud to the arms D of the fly frame, receive the same circular motion as the fly frame; but at the same time they are left free to revolve round their own centres, which they do in a greater or less degree according to the varying friction of the grinding surfaces. The grinding motion being thus obtained, sand and water are constantly applied, until the surface of the glass is found upon examination to be free from all defects; the sand is then washed off the glass, and the first stage of the smoothing process is commenced on the same machine by substituting the coarser qualities of emery in place of the sand. The plate of glass is then removed from the bench, turned over and replaced on the bench, and submitted to the same process on the other side. The speed at which the fly frame is driven is about 40 revolutions per minute. It will be seen that the runner frame B, Fig. 2, is not sufficiently large to act upon the entire surface of a large plate of glass at one time; it is therefore necessary to divide the operation and shift the position of the runner frame as the work requires it, by inserting the centre stud of the runner frame into a different portion of the slot between the fly-frame bars D.

Until the last few years the principal part of the operation of Smoothing was effected by manual labour, the operation being performed by rubbing two pieces of glass together and applying emery powder between them. Great care is requisite as the work approaches completion that no scratching shall take place; and it is on this account that hand labour is considered absolutely necessary for finishing the process, the slightest scratch being immediately felt by a practised hand, whilst a single stray particle of grit on a machine would spoil the whole surface before it was perceived.

About 1857 Mr. Crossley introduced a machine for smoothing the plates of glass, which so far succeeded that the nicety of the hand touch is only required for the final part of the operation. This smoothing machine, shown in plan in Fig. 3, Plate 58, is exceedingly simple and inexpensive, consisting of a long wooden bar C, connected at one end to a crank E on an upright spindle, and extending over the stone bench A on which the plate of glass is laid; two runner frames B of wood are attached to the bar C, and on the underside of each frame is fixed another plate of glass; these are then laid upon the glass on the bench. In this case the runner frames B are only allowed to partake of the motion given to them by the bar, and are not left free to revolve round their own centres as in the grinding operation previously described. The centre of the bar C between the two runner frames is kept in position by a radius rod G secured to a fixed bracket on one side of the bench, at right angles to the direction of the bar. The crank E being set in motion, the bar and runner frames receive a movement somewhat similar to the figure 8, which is very similar to the motion given in manual labour. One advantage of this machine is that two surfaces of glass are finished at one operation. The space between the two runner frames B is found very convenient for applying the emery and also ascertaining the progress of the work, without having to stop the machine.

The machinery used in the Polishing process remains the same in principle as that originally constructed for the purpose. Each machine consists of a strong cast iron frame H, Figs. 4 and 5, Plate 59, about 18 feet long by 10 feet wide, containing a series of small rollers, upon which is placed a wooden table I with two racks on the underside; suitable gearing is connected to these racks, to give the table a slow alternate lateral motion so as to bring every part of the plate of glass under the action of the rubbers B. The plates of glass are fixed upon the table I by plaster of paris, and the ends of the table move between slide blocks secured to the main frame H, so as to prevent the action of the rubbers from displacing it. The rubber blocks B are pieces of wood covered with felt, and provided with a central spindle and adjustable weights to regulate the amount of friction; a number of these blocks are secured to two moveable bars D, running on rollers J J at each end of the table I, and driven by a short shaft E with cranks at the ends set at right angles to each other. The rubber blocks are thus worked transversely to the motion of the table; and by applying the polishing powder in a liquid state the surface of the glass is gradually brought up to the requisite degree of polish, both sides of the plate successively being subjected to the same operation.

About 1857 experiments were commenced at the British Plate Glass Works at Ravenhead with an entirely different class of machinery for Grinding and Smoothing plate glass, with the object of increasing the production, reducing the cost, and also completing the process of smoothing upon the same machine on which the glass is ground, so as to obviate the necessity of a separate machine for smoothing, and also save the expense and loss of time in removing and refixing the plates of glass. The new grinding and smoothing machine is shown in Figs. 6 and 7, Plate 60, and consists of a revolving table K, 20 feet diameter, fixed upon a strong cast iron spindle L, and running at an average speed of 25 revolutions per minute, driven through an intermediate upright shaft M from the main line of shafting N by a pair of bevil wheels, and friction cone O for throwing in and out of gear. This arrangement of gearing for driving the table was made by Mr. Daglish, and was adopted in order to obtain a long spindle L for the table, of a length equal to the semi-diameter of the table, and at the same time to keep the main line of shafting N continuous, for driving a series of tables in one room. Over the top of the table a strong timber bar P is fixed, about 10 inches from its surface; and on the two opposite sides of this bar are bolted two notched plates of cast iron Q, one on each side of the centre of the table. The notches are for receiving the centre studs of the runner frames B, which are very similar to those used on the old class of machinery; and the runners can thus readily be moved nearer to or further from the centre of the table, as circumstances require, by shifting the stud into a different notch. The only motion which these runner frames have is round their own centres, and this is given to them by the excess of friction on the side furthest from the centre of the table over that on the side nearest to the centre, this excess being caused by the greater velocity of the portion of the table further from the centre. It is evident that the amount of grinding action is considerably greater on this machine than upon the old one, both from the increased velocity of the runner frames themselves, and also from the double amount of movement obtained by the revolution of the table K and the runner frames B. The idea of driving the runner frames themselves, as well as the table, was conceived at an early stage of the experiments; but on being put to the test, it was found that the unaided movement of the runner frames adapted itself to the work to be performed far better than any compulsory motion could do. It has also the advantage of leaving the surface of the table free and unencumbered with any machinery, and consequently facilitates the operation of laying and removing the plates of glass: the whole of the driving machinery is also covered over and thus protected from the injurious effects of the sand and water thrown off from the edge of the table in working.

This machine has been found to answer equally well for smoothing as for grinding; and this is perhaps its most successful feature in a commercial and economical point of view. Both these processes are now completed on it at the Ravenhead Glass Works, the finishing portion of the smoothing operation alone being effected by manual labour for the reasons before stated. The plates of glass being generally oblong in form, it was found that the machine in its original shape, having a circular table K for carrying the glass, as shown by the dotted circle in Fig. 7, Plate 60, entailed considerable waste in filling up the area of each table for grinding; and it was then determined to alter the shape to that of an unequal sided octagon, or square with the corners taken off, as shown in the plan, Fig. 7: no difficulty has been experienced in the process of grinding from this alteration in form, whilst the amount of waste in making up the tables has been considerably reduced, and greater facilities are obtained for grinding large plates. The amount of wear and tear on this machine has been found to be very small in comparison with the old machines, owing to the small number of working parts, the large extent of bearing surface, the smoothness of the motion, and the complete balancing of the table. The quantity of glass finished upon one of these machines per week is from 1200 to 1500 square feet, which is about one third more than the old machines are capable of doing, due allowance being made for the difference of area in them.

The first point to which attention should be directed for working out further improvement is the method adopted in casting the plates of glass, and the machinery employed to carry out the process. It has been stated that the plates of glass in their rough state are very irregular, so much so that about 40 per cent. of the glass is ground away in the subsequent processes, which is a serious waste of material and entails a great expenditure of time and material in the process of grinding; it is therefore worthy of consideration, whether some improvement may not be carried out in this direction by obtaining the plates of glass smoother in the first instance. The grinding and smoothing operations are believed to be now improved upon the previous practice, though there is no doubt room for further practical suggestions and appliances. The polishing process has been tried to a limited extent on the revolving table last described, but without any practical advantage: the present system is no doubt theoretically correct, as the action of the rubbers is regular and uniform over the whole surface of the glass, thus keeping up a uniform temperature; but some motion producing a continuous movement of the rubbers, instead of the present alternate movement, would no doubt reduce the wear and tear and require less power, and would probably also be found capable of a higher velocity, resulting in an increase of production, provided the other requisite conditions of the process were complied with.

Mr. **Windus** exhibited specimens of the plate glass from the several stages of the manufacture, in the rough state after casting, and after each of the processes of grinding, smoothing, and polishing. He also showed specimens of plate glass made from English and from French sand, together with samples of the sand from which they were made, showing the lighter colour and greater purity of the French sand.

Mr. F. J. **Bramwell** observed that reference had been made in the paper to the highly satisfactory working of Mr. Siemens' regenerative gas furnace as applied for melting the materials to make the glass at the Ravenhead Works: he had, as engineer to the company, recommended the adoption of that furnace for the purpose, being convinced of the great advantages that would be found to attend its use, and the first furnace on that construction had now been in constant work for fifteen months, and a second and larger furnace had been erected in May last, which had also been in constant work since that time. These furnaces he believed left nothing to be desired as far as regarded the melting: but in other respects he thought the process of making plate glass was at present in a most unsatisfactory position, and some improvements seemed to be much wanted in the mechanical contrivances used in the manufacture, though he must admit it was more easy to make that assertion than to show how the improvements were to be effected. A serious objection to the present arrangements was the great amount of handling that the plates of glass had to undergo in the several processes, which was evidently an important point when it was considered that the large plates fetched a higher price per square foot than smaller ones, and therefore it was desirable to avoid the risk of having to cut up large plates into smaller sizes on account of fractures. Under the present methods however the risk of fracture was great, from the number of times the plates were handled: on leaving the annealing oven the plate was handled once in conveying it to the grinding machine and bedding it there, and afterwards a second time in turning it over for grinding the second side; and similarly it had to be twice handled for each of the subsequent processes of smoothing and polishing, making six times of handling altogether before the plate of glass was finished on the machines, after which it had still to be twice handled in the final operation of hand cleaning. All these processes he considered ought to be effected without more than twice laying the plate, once for each side; or even without laying the plate at all, by working on both sides of it simultaneously: and in this respect therefore he thought there was a wide field open for improvements in the plate glass manufacture.

The revolving grinding table that had been described was a decided improvement upon the old fly-frame grinding machine, since in all mechanical operations it was better to get rid of a reciprocating action wherever practicable, and replace it by a continuous circular motion. The new construction of grinding table was preferable to the old grinding benches, on account of its protecting all the machinery below it, so that the working parts and bearings were not exposed to injury from the grit thrown off profusely from the grinding table. A further advantage was the large size of the table, 20 feet diameter, which afforded room for working on the whole surface of a large plate of glass at once.

A serious cause of loss at present in the manufacture was the very large proportion of the glass that had to be removed in the process of grinding in order to obtain a level surface of the glass. The undulations on the surface of the plates before grinding could not he considered be produced by the roller on the casting table, as had been suggested, because the roller was of great weight and was moved forwards steadily, running at each end on a smooth strip of iron laid along each side of the casting table, by which the thickness of the plate of glass was determined; the surface of the glass appeared level before the plate was put into the annealing oven. The undulations after annealing were not in parallel furrows across the plates, but were in the form of hills and hollows, altogether irregular in size and position. It therefore appeared that the glass in annealing must contract irregularly, causing this unevenness of the surface, particularly on the side which had lain uppermost in the annealing oven, in consequence of which so large a proportion of the glass had to be ground away as waste in order to obtain a level surface. In the old annealing ovens the plates had to be left a long time till the oven had cooled down of itself; but the ovens were now built with air channels under the bed, through which a current of cold air passed, so that the heat was reduced as quickly as was practicable without injury to the glass, whereby a great saving of time was effected. No method however had yet been devised for laying the plates one on another in the annealing oven, and consequently a large area of surface was required in the ovens in order to lay them all separately, some of the ovens being as much as 50 feet long for the purpose of annealing six large plates of glass at a time: the ovens were well designed for uniformity of heat in all parts, notwithstanding their great size.

Mr. R. **Pilkington** thought the reason of the uneven surface produced on some of the glass plates in annealing was that the oven was made too hot for the first plates that were put into it, in order that it might be hot enough for the last ones; and consequently the earlier plates had not become sufficiently set with a uniform degree of hardness before going into the oven. The glass certainly went into the oven quite smooth, and the unevenness must therefore arise in the annealing. At the St. Helen's Plate Glass Works they made what was known as Hartley's plate, fluted plates of glass ½ inch thick, and these were annealed by being piled on the edge in a vertical annealing oven, as they were strong enough to stand on the edge in consequence of their corrugated form. A plan had also been tried of laying the flat plates one upon another in the annealing oven, by means of a lowering table in the oven; but the objection to this plan was that if the plates were at all too hot they stuck together and could not be separated again without breaking.

Mr. J. **Fernie** enquired whether in rolling out the glass on the casting table the roller was passed over the glass at a uniform speed without any jerking action: he thought if the roller was stopped or moved slower at any places that would account for the uneven surface, because the continued heat of the annealing oven would allow time for the glass to expand again at those places, when it might assume the irregular surface that was noticed.

Mr. F. J. Bramwell replied that although the roller was moved over the glass by hand there was no jerking action or irregularity in the motion; and therefore he did not think the uneven surface could be accounted for in that way, but must be due entirely to the unequal effect of the heat upon different portions of the plates in the annealing oven. It was true that just before the plate was slid off the casting table into the oven, the glow of the newly rolled hot glass had the appearance of being in parallel stripes across the plate, although at that time the surface was really level; but after the annealing, the unevenness of surface did not show itself in parallel furrows, but in irregular hollows over all parts of the plate, as had been already mentioned.

Mr. W. Danson enquired where the foreign sand was obtained that was used for making plate glass, and whether sand from Sydney in New South Wales was ever used; this had been imported about thirty years ago for the purpose, but was not found to answer at that time.

Mr. Windus was not aware whether the sand from Sydney had been used for glass making: the foreign sand used for the purpose, of which a specimen was now exhibited, was from Fontainebleau near Paris.

Mr. R. Pilkington observed that the great cost of importing foreign sand for making plate glass was a heavy expense in the manufacture. The French sand cost about 21*s.* per ton, as compared with only 3*s.* per ton for English sand including cleansing by washing; but the latter when washed clean of impurities was good enough for the manufacture of sheet glass.

Mr. D. Adamson suggested that it would be desirable to ascertain the nature of the geological strata in which the fine Fontainebleau sand was found: for in England there were so many varieties of sand along the coasts, and so great a range of geological formation was developed throughout the country, that no doubt if the peculiar qualities of the French sand were fully investigated some of the English river or coast sands might be found to be equally suitable for plate glass manufacture.

Mr. J. SILVESTER enquired whether the use of iron plates laid upon the upper surface of the glass had been tried for flattening the glass in the annealing oven: these were used successfully for flattening sheet steel, which was rendered necessary by the tendency of the sheet to buckle in hardening, but if made perfectly flat during the process of tempering it remained so afterwards; and he thought the same plan might answer for flattening plates of glass.

Mr. F. J. BRAMWELL thought there would be a good deal of difficulty in employing iron plates as covers for keeping the plates of glass flat in the annealing oven, on account of the large size of plates that would be required, 180 inches long by 80 to 100 inches wide. The expense too would be large, since as many iron covers would be required as there were plates of glass, say half a dozen in each oven. Moreover the iron would have to stand heating up to a low cherry red heat every time of charging the annealing oven.

Mr. R. PILKINGTON did not think iron plates had been used either to maintain an even surface of the large sheets of cast plate glass or to form the bed upon which the glass was to be annealed. With regard to the sand used for making the glass, the main difference between the foreign and English sand was that the former was entirely free from iron, while the English sand was always found to be impregnated with it; and no cleaning process was successful in getting rid of the iron. The foreign sand from Fontainebleau was found on clay. In washing the sand for use the apparatus employed was similar to that which had been described as used for washing the sand for the filter beds of the Liverpool Water Works: but for the water works the finest sand was washed away, and only the coarser quality was retained for use in the filter beds; whereas for glass making it was the finest sand that was wanted, and the coarser portion was rejected.

Mr. F. J. BRAMWELL remarked that in grinding the emery that was used for smoothing and polishing the plates of glass it had formerly been customary to grind it dry under edge runners; but recently a valuable improvement had been made by grinding it in a stream of water, the whole apparatus being otherwise the same. The saving of time thus effected was so considerable that two days a week were now sufficient to grind all the emery formerly ground in a week; while at the same time there was no waste of the emery from the fine dry powder flying about in the air, and the absence of this dust in the works caused a great improvement in the workmen's health. The reason of the saving of time in grinding the emery with a stream of water was the same as in the case of grinding corn with an air blast between the stones: directly any portion of the corn was ground so fine that it ought to leave the stones, the blast carried it away, so that the stones were always operating upon nothing but what they ought to grind; and in the same way the stream of water removed the fine emery powder as soon as ground, and left only the coarser particles under the stones, thus producing a most satisfactory result in economy of time.

The subsequent process of sorting or separating the several qualities of the ground emery according to the degree of fineness of the powder was also of great practical importance in plate glass manufacture. The method adopted was the same as that used for sorting or washing the ore at lead mines: the different sizes of particles were separated by the action of gravity, by means of a series of streams of water of diminishing velocity, through which the particles of emery sank according to their size. This was one of the most simple and beautiful contrivances that he was acquainted with, and proved completely successful in preventing any of the coarser particles from getting mixed with the finer sorts of emery powder.

Mr. W. E. Newton remarked that for separating substances having different sizes of particles there were two methods that might be employed, the wet and the dry. The former had already been described in the case of separating the particles of emery by streams of water running at different velocities; in the dry method the separation was effected by a blast of air. The latter plan was devised and employed by Mr. Bentall of Weybridge for separating into different degrees of fineness the coal dust which he used in his foundry for making castings, whereby he obtained castings much superior to those generally produced for agricultural purposes. The coal was crushed by edge runners to a great degree of fineness, and an air blast from a fan blew the dust into a long covered box or chamber about 30 feet long, the bottom of which was divided into four lengths or compartments: the finest dust was carried to the extreme end of the chamber and deposited in the furthest compartment, while the coarser and heavier particles fell into the nearer compartments, according to their respective sizes, the coarsest falling nearest to the grinding apparatus. The process was found most satisfactory in producing a distinct and accurate separation of the different sorts of coal dust; and he had himself examined with a microscope the particles of dust deposited, and found them very uniform in size at any one part of the long chamber. In this process also the ground coal dust was removed immediately from the grinding apparatus by the air blast, instead of remaining there to clog the grinding. The same method would he thought be applicable for separating emery into its different degrees of fineness for polishing glass, if it were preferred to separate it dry instead of employing water for the purpose.

The CHAIRMAN thought it was matter of regret that no means had yet been arrived at for making the best plate glass from home sand, instead of foreign sand; and he suggested that some mechanical mode of bleaching the sand might be discovered, to render the English sand as good for the purpose as the foreign sand: the application of heat might perhaps be tried, as that was known to produce a great difference in the colour of many materials, such as clays and other earths.

With regard to the origin of the waviness on the surface of the glass plates after leaving the annealing oven, it had been stated that this unevenness did not exist when the roller left the surface of the glass on the casting table, but that it became developed during the gradual cooling of the plate in the annealing oven; and it occurred to him that possibly the glass at the time of casting might be in a viscid or plastic state, like gutta-percha, instead of being completely and uniformly liquified throughout the entire mass, the result of which would be that it would yield under the roller, but the rolled plate would be irregular in density and would thus become uneven during annealing by swelling up again at various parts. If however the unevenness could be prevented by packing the plates of glass between iron plates in the annealing oven, as had been suggested, he thought the saving effected by the smoother surface in the subsequent grinding process might make up for the additional expense of the iron plates in the first instance; and the number of iron plates required would be only one more than the number of glass plates to be laid between them, if they were laid in a continuous pile.

The particulars given in the paper regarding the increase in the manufacture of plate glass during the last few years afforded another and a very clear illustration of the effect of cheapening any article in causing a great extension of its use. He moved a vote of thanks to Mr. Daglish for his paper, and also to Mr. Windus, which was passed.

The following paper was then read:—

DESCRIPTION OF THE NEW IRON WORKS AT GROSMONT.

By Mr. HIRAM C. COULTHARD, of Blackburn.

In the Cleveland iron district, where the Grosmont Iron Works forming the subject of this paper are situated, there are at present 63 blast furnaces in full operation, 17 furnaces not in operation, standing for repairs or other causes, and 11 furnaces in various stages of progress. The Grosmont furnaces have been erected by Messrs. Bagnall, and the general working arrangements for them were made by the manager, Mr. Barnes, and the writer of the present paper; and upon the latter devolved the arrangement of engines and boilers, &c.

Grosmont near the coast of Yorkshire is situated about 7 miles from the port of Whitby, 20 miles from the Durham coalfield, and about the same distance from the lime district of Pickering, whence the supply of lime is derived. Fig. 1, Plate 61, is a general plan of the entire works, which are adjacent to the main line of railway from Whitby to Castleton, joining the North Yorkshire and Cleveland Railway, and thus in connexion with the Newcastle and Durham coal and coke districts. A siding from the main line runs into the works.

These blast furnaces are believed to be constructed on a very efficient and economical plan for the purposes intended. Each furnace is capable of producing 250 tons of pig iron per week, allowing for stoppages on Sunday. Fig. 2, Plate 62, is a vertical section of one furnace, and Fig. 3, Plate 63, shows an enlarged vertical section of the top and bottom of the furnace. Figs. 4 to 8, Plate 64, are transverse sections of the furnace at the tuyeres, tapping hole, and hearth, and through the body of the furnace.

Each furnace measures 18 feet diameter at the boshes, and a total height of 63 feet from ground line to level of charging floor. The foundations were dug out to a depth of about 9 feet, to rock on one side and hard blue clay on the other, the ground sloping in the direction of the dip of the rock. The stone foundations both for the hearth and casing of the furnace are shown in the vertical sections, Figs. 2 and 3, Plates 62 and 63, and consist of ring courses of masonry built on concrete, about 26 feet diameter, each course being bound by a wrought iron ring, 5 inches wide and $\frac{7}{8}$ inch thick, Fig. 3. In the interior of the uppermost ring course is built the firebrick hearth A, Fig. 3; the blocks of which this is formed are shown in plan and vertical section in Figs. 6 and 7, Plate 64. These blocks are set in ground fireclay in a moist state, special care being taken to secure a perfectly homogeneous mass, as the whole of the superstructure of the furnace and its contents when in working order, weighing about 1200 tons, rest upon this foundation. On the top course of masonry the foundation plates of cast iron, 3 feet 6 inches square and 4 inches thick, are bedded in fireclay, to which are bolted the cast iron columns B B, Fig. 3, 17 inches diameter, for carrying the superstructure. These columns are united at the top by a cast iron ring or cornice C in segments, 3$\frac{1}{2}$ inches thick, each segment having a semicircular snug cast on its under side, which when the work is joined together fits into the top of the column B, thus binding the whole of the segments into one ring.

The entire lining of the furnace inside is of refractory firebrick D, Fig. 3, Plate 63; the furnace is cylindrical on the outside and entirely cased with wrought iron plates E, $\frac{3}{8}$ inch thick at the bottom of the furnace, and towards the top of the furnace diminished in thickness to $\frac{5}{16}$ inch. This casing weighs about 30 tons and costs about £400, and is now being generally used in place of the massive stack of masonry formerly used. There are ten cast iron pillars B for carrying the super-structure, placed at a distance of 7 feet apart, except where the tapping hole is situated, where the distance is increased to 10 feet, as seen in Fig. 4, Plate 64. Brackets are cast on these pillars, Fig. 3, for the purpose of carrying the circular pipes that convey the blast and water round the furnaces for distribution to the various tuyeres. There are five tuyeres to each furnace, one of which is shown in longitudinal section in Fig. 9, Plate 64.

At the top of the furnace a wrought iron plate cornice F is fixed, Fig. 3, Plate 63, forming the charging floor; and the two furnaces are connected by means of two longitudinal wrought iron girders 4 feet and 3 feet deep respectively, the larger one prepared to receive the wrought iron beams that form the roadway of the incline up which the materials for smelting are drawn by means of a pair of fixed horizontal engines. These girders are united by nine intermediate cross girders of wrought iron, and when covered with plates form the roadway of the charging floor, having a screen 3 feet 6 inches high running round for protection.

The throat of the furnace, Fig. 3, Plate 63, is adapted for taking off the waste gas, which is collected in a wrought iron tube G, 5 feet diameter, which extends down the throat of the furnace about 5 feet and is lined inside and cased outside with refractory firebrick 6 inches in thickness. This tube is fixed to and supported by a crown or dome built in the throat of the furnace, of specially moulded lumps of fireclay, supported by six buttresses built of the same material. The crown has six openings formed at the sides for charging purposes, and one opening in the centre, through which the gas passes into the tube G. There is the usual brick chimney at the top of the furnace, with wrought iron swing doors corresponding with the openings in the crown. The gas is conveyed from the furnace top to the boilers, hot-blast stoves, &c., by a wrought iron tube 5 feet 6 inches diameter, large enough to take off the gas from two additional furnaces; and square boxes H, Fig. 1, Plate 61, are fixed at intervals along the tube to allow for expansion. A flap valve I, Fig. 3, Plate 63, opening outwards for cleaning purposes is fixed at the end of the tube over the furnace.

Figs. 10 and 11, Plate 65, show a vertical section and sectional plan of one of the hot-blast stoves. Three of these are built to each furnace, of common brick made on the estate, lined with refractory firebrick, and externally bound firmly together by wrought iron hoops 4 inches wide and ⅝ inch thick, placed at intervals of 3 feet. The stoves are heated by the gas being admitted at the top J, and a small fire is kept on the grate at the bottom for the purpose of ensuring that the gas is always ignited. Four flues K K, Fig. 11, pass away from the bottom of the stove to the main chimney flue L, Fig. 10, which is in connexion with the chimney stack, Fig. 1, of 180 feet height. A simple disc valve J is fixed at the top of the stove where the gas enters, to cut off the supply of gas from the stove at any time. The pipes M, through which the blast passes, consist of ten pairs to each stove, 12 inches diameter, each pair being arched at the top and united at the bottom by connecting foot-boxes, thus forming one continuous course of pipes for the blast to pass along. The blast enters on one side of the oven, and after circulating through the pipes M passes out at the other side into the main pipe N for the service of the tuyeres, as shown by the arrows. A stop valve O serves to cut off the communication of each stove with the blast main, which is 5 feet 6 inches diameter and thus forms also the blast reservoir. The temperature of the blast is from 600° to 700° Fahr., and the quantity blown by each engine is 6000 cubic feet per minute at a pressure of 3 lbs. per square inch. These hot-blast stoves have been found most effective; from the enlarged capacity of the pipes, the blast is much longer in passing through them, and consequently they are not required to be kept at such a destructive heat. The writer understands that these stoves are extensively used in Staffordshire and with the best results.

The blast is supplied by three direct-acting high pressure engines, quick moving, having air cylinders 57½ inches diameter with a stroke of 3 feet. Fig. 12, Plate 66, is a transverse section of the boiler and engine house. Two engines P are sufficient for the work of two furnaces, a third one being provided in case of emergency. The reason for separate engines being used is that in the case of an accident to the blowing engine, when only one engine is used, the whole of the furnaces are thrown idle; moreover the cost of machinery for two furnaces is much less in these engines, taking into consideration the expensive nature of the stonework &c. required for the foundation of one large beam engine. The only foundation required for these engines is about 3 feet depth of brickwork, with a framework of timber on which to bolt the foundation plates.

The engine house is of red brick with mouldings of white brick, and presents a good appearance; the roof is formed by the water tank R, Fig. 12, Plate 66, which contains the water supply for the tuyeres, pig beds, &c. In the engine house is fixed a travelling crane S for the convenience of examining any portion of the engines; this is found a most useful appendage. The water supply is derived from the river Esk by two lift pumps having trunk cylinders 7¼ inches diameter. The boilers T, Fig. 12, Plate 66, are five in number, each 73 feet long by 5 feet diameter, of the plain egg-ended form, heated by the waste gas from the blast furnaces. They are suspended by means of cast iron bridges from the top of the boiler seats, and are fed by three donkey engines, all connected to one pipe over the boilers. The steam pressure is 60 lbs. per square inch above the atmosphere.

A steam lift is fixed in the works in the position shown in Fig. 1, Plate 61, for the purpose of raising the minerals from the line of railway to the top of the calcining kilns.

Mr. SAMPSON LLOYD thought the new ironworks described in the paper were a good illustration of the modern improvements that were now being generally adopted in ironworks. The blast furnaces appeared to be built according to the construction now generally in use; but for taking off the gas from the open top of the furnace a variety of plans had been adopted, and the main peculiarity of the arrangement shown in the drawings appeared to be the use of a wrought iron tube for the purpose, inserted into the top of the furnace and lined inside and outside with firebrick. That plan had now been in use for some time at Messrs. Schneider's furnaces near Ulverstone, where the furnaces were not stopped on the Sunday, but worked continuously from the beginning to the end of the week. But where the furnaces stopped on the Sunday, as was the case at the new works now described, the alternate contraction and expansion of the firebrick was a serious difficulty to contend with, causing the firebrick to crack and become detached, and necessitating frequent renewals of portions of the lining. Moreover the usual plan had been to make the extremity of the tube, where it dipped into the materials in the top of the furnace, of cast iron, that it might have greater durability under the action of the flames arising from the gas burning out of the top of the furnace around the tube; and the cast iron tubes were generally found to last from 12 to 18 months before requiring renewal.

The circular hot-blast stoves shown in the drawings were a construction that had been in use for a considerable number of years without being open to any great objection; but they were not the kind that was generally preferred in South Staffordshire, nor had they been found the best at some of the new ironworks lately erected at different places in the North of England. The long oven had been found in practice better than the circular oven, in respect both of economy of fuel and temperature of blast obtained; and in the present instance the temperature of the hot blast, 600° to 700° Fahr., was not so high as was now generally used for hot-blast furnaces: the heat however was regulated in different districts according to the particular requirements of the iron.

With regard to the most suitable description of blast engine to be employed, there was a great variety of opinion. Where engines had to run day and night from year's end to year's end, keeping up a uniform pressure of blast, his own experience was that a large engine working with a slow motion was the most economical in the long run. The small quick running engines described in the paper were certainly the cheapest in the first instance, but he doubted whether they would be found so in working over a series of years.

Mr. T. W. Plum remarked that the gas tube inserted in the mouth of the blast furnace appeared to be carried by an arch or false top built in the mouth of the furnace, with openings round the tube for charging the furnace; and he enquired whether that plan was not liable to difficulties from the charging holes getting stopped up occasionally by accident. He feared also some inconvenience would be caused in winter from the water getting frozen in the large open water tank forming the roof of the engine house, unless some provision were made for preventing such an occurrence.

Mr. F. J. **Bramwell** said he had seen the same arrangement of the gas tube in the top of the blast furnace at Messrs. Schneider's furnaces working the hæmatite iron; the tube was coated with firebrick inside and outside, in the manner shown in the drawings, and carried on six flying buttresses built in the throat of the furnace, so that the mouth of the furnace was in no way closed up except by the gas tube. He understood from the manager of the works that not the slightest trouble had been experienced with that arrangement, and that nothing could be more successful than that mode of taking off the waste gas.

Mr. E. **Reynolds** enquired whether the blast furnaces in the Cleveland district were worked with coal or with coke.

Mr. D. **Adamson** said that throughout the Cleveland district the blast furnaces were all worked with coke, and no coal at all was used in them; the same was the case in the Wear district and the North of England generally. One common feature of the ironworks in the North was the use of quick short-stroke blast engines, in place of the large long-stroke engines generally employed for blowing the Welsh furnaces, which were considered more advantageous in that district; but in his own opinion a vertical direct-acting high pressure engine with moderately long stroke was much more economical in working for supplying the blast than a heavy beam engine.

In reference to the method now described of taking off the waste gas from the top of the blast furnace, leaving the space round the gas tube open for the escape of the superfluous gas, he questioned whether that plan went far enough in the matter: for if the gas could be employed with advantage for so many purposes, for heating the steam boilers and hot-blast stoves and calcining the ironstone, he thought none of it ought to be left to escape from the mouth of the furnace, but the whole should be collected and saved. The gas might for instance be more generally employed than at present for calcining the ironstone, for which he thought it was particularly suitable, giving the means of calcining all the material uniformly. The great aim in blast furnaces was to get uniformity of heat in all parts at the same level, and an important step would be effected in that direction if the ironstone were uniformly calcined beforehand by the application of the waste gas, and then conveyed direct to the blast furnace without having to lie exposed to rain and weather, which he believed would obviate some of the difficulties that had at present to be contended with in the blast furnace.

The blast furnaces described in the paper must he thought be working well to produce the make that had been stated of 250 tons of iron per week from each furnace. That was a very large production for the Cleveland district, because to produce one ton of iron from the Cleveland ore required 3¼ tons and upwards of ore, 15 or 16 cwts. of limestone, and 27 or 28 cwts. of coke; making nearly 5½ tons of material per ton of iron, so that an enormous quantity of material had to pass through the blast furnace in order to produce 250 tons of iron per week. In the hæmatite district on the other hand the quantity of ironstone did not exceed 1¾ tons per ton of iron made, and the quantity of limestone was only 4 to 5 cwts., while the coke required was from 17 to 25 cwts.; making only about 3 tons of material per ton of iron.

The working conditions of the blast engines must always depend in a great measure on the pressure of blast that was employed, which had been stated in the paper to be 3 lbs. per square inch at the Grosmont furnaces: but at another of the ironworks in the Cleveland district, Messrs. Warners and Co.'s, Norton Furnaces, near Stockton-on-Tees, he found that the pressure had been reduced from 2¾ lbs. down to only ½ lb. per square inch, and that the make of iron from the furnace was rather increased, while the work done by the blast engine was very much less. This was such a change upon the current practice in blast furnaces as to be worthy of careful consideration. The size of the tuyeres had at the same time been increased from 3 inches to 6 inches diameter, admitting a greater volume of air to the furnace, and they would have been made still larger had they not been limited by the size of the blast main, which was only 9 inches diameter. It was intended however to enlarge the tuyeres further to 9 inches diameter, and reduce the pressure of blast from ½ lb. to ¼ lb. per square inch. At those works the ore used was the Cleveland ironstone, and also the Rosedale magnetic ironstone, the only magnetic iron ore yet discovered in the Cleveland district.

Mr. T. W. **Plum** asked how the quality of the iron produced was affected by the reduction of pressure of the blast. It was generally understood that a reduction in pressure of blast improved the yield of the furnace, that is the quantity of iron obtained from the ironstone, and also the quality of the iron, but reduced the total make of the furnace in quantity.

Mr. D. **Adamson** said that the result of reducing the pressure of blast had been favourable on the whole to the brand of iron, as the reduced pressure contributed materially to keep the furnace steadily on foundry quality of iron, without so much liability to fluctuation of quality under atmospheric changes as in other furnaces with a higher blast, where a cold east wind or rain would bring the quality down from No. 1 to No. 3 immediately. At the works he referred to the engine power was not yet fully developed, and the volume of air at present supplied was only about one half more than at the ordinary higher pressure. The blast engines were horizontal, with a moderately long stroke; but he considered the air cylinders never worked so well in a horizontal as in a vertical position, as the vertical air cylinders had less wear, and were less exposed to grit and dust accumulating on their rubbing surfaces.

Mr. F. J. **Bramwell** remarked that, in reference to the question of taking off only part of the waste gas from the blast furnace, it did not follow that because so much advantage had been found in taking off part of the gas therefore the whole of it ought to be taken off: for he believed the surplus gas left to burn out round the gas tube was not to be considered as wasted, since a certain amount of combustion was wanted in the mouth of the furnace to prepare the charges of ore as they were thrown in, by heating them; and if there were no combustion in the furnace mouth, that preliminary operation would be lost and the quality of the iron made would be impaired. Moreover the open space left round the gas tube obviated all difficulty in charging the furnace, the materials being filled in through that space just in the same manner as in an ordinary open-topped furnace. At Messrs. Schneider's works near Ulverstone all the engine power and hot-blast stoves for the entire works were supplied by taking off only a portion of the gas, and therefore there was no use in trying to take off more, while there might on the contrary be harm in doing so. At those works also exhausting fans were used to aid in drawing off the gas from the blast furnaces; and at some ironworks in France an arrangement of collecting troughs was added to catch the dust that was brought down with the gas taken off.

With regard to the make of the present furnaces, he was glad attention had been called to the large proportion of ironstone, limestone, and coke, that was required for producing the 250 tons of iron per week; because in estimating the duty of a blast furnace it was necessary to take into account not merely the actual production of iron per week, but also the nature of the materials employed, and the relative quantities consequently required to produce a ton of pig iron. In the most favourable case that he knew of, where the hæmatite ore was smelted, the make had amounted to as much as 600 tons of pig iron per week from a single furnace, owing largely to the small proportion of materials required in working that particular ore.

Mr. J. FERNIE observed that another reason for leaving the mouth of the furnace open all round the gas tube was that, if the top were all closed in for taking off the whole of the gas, there was more liability to injury occurring in the event of any explosion of the gas; but the open space left round the gas tube in the present arrangement acted as a permanent safety valve, through which the force of an explosion would find ample vent without any mischief being done.

Mr. Sampson Lloyd remarked that at ironworks having two or three blast furnaces in regular work the production of gas from the furnaces was more than was wanted at present, unless some means could be found out for making the gas available in the puddling and heating furnaces, in which case it might perhaps all be made use of. But while the gas was employed only for raising steam for the blast engine and heating the hot-blast stoves, the gas given off from one or two furnaces was quite sufficient to supply the heat for blowing four or five furnaces, and therefore the gas from the remainder of the furnaces must all be wasted at present, and there would be no use in closing in the tops of the furnaces in order to take it off. Moreover the applicability of the close top depended much on the quality of the materials employed in the furnace. Where a very hard coke was used and it was not necessary to be particular as to the quality of iron made, a close-topped furnace might be found satisfactory: but where a soft coke was employed and it was of particular importance that a good quality of iron should be maintained, the open top must be adhered to, in order to avoid interfering with the working of the furnace. For though a blast furnace had the appearance of being so rough in working, it was in practice most sensitive to the slightest variations of circumstances; and the result of many years' experience with close-topped furnaces had been that it was found impossible to ensure making the best iron continuously when the top of the furnace was entirely closed in for taking off the gas. The method now shown of taking off the gas from open-topped furnaces was really so simple and so effective that there was no further advantage to be gained by closing in the top of the furnace; and he thought the open-topped plan would be found applicable to blast furnaces under all circumstances of working, without detriment to the make of iron. With the open top explosions of gas were not at all to be feared, as regarded the furnace itself; and with a proper provision of safety valves along the gas main there was no risk whatever, as an explosion produced no further effect than merely a "pop" as it was called by the workmen.

The theory of working the blast furnaces with a low pressure of blast was by no means a new one. In one of the earliest papers read before the Institution the fan blast had been advocated in place of the blowing cylinder for blowing blast furnaces. But experience had all tended in the contrary direction; for with common materials in the furnace it was found that, with a low blast pressure of only 1 to 1½ lbs. per square inch, not only was the yield of iron obtained much less in quantity, but the working of the furnace was generally not more economical than with the ordinary blast of 3 to 3½ lbs. pressure per square inch. For producing the blast his own experience for a number of years led him to prefer the long-stroke large blowing engine as superior to a small short-stroke engine running at a high speed.

Mr. J. Fernie observed that the length of the boilers described in the paper, 73 feet, appeared to him great, and much beyond what was generally employed.

Mr. D. Adamson said the tendency in the North of England was to increase the length of boilers when heated by the waste gas from blast furnaces, and he had recently made some for that district as long as 85 feet and 5 feet diameter, each being supported by 20 suspension rods from cast iron beams over the top of the boiler. It must be borne in mind that in boilers heated by the waste gas from blast furnaces the products of combustion passed off at a comparatively low temperature but were large in quantity, and a long length of flue under the boilers was therefore necessary, with a large flue area, in order that the heat might be more effectually absorbed. He was not aware of any serious objection to long boilers in working, when adapted for this purpose; nor were they more expensive in proportion to their heating surface than boilers of ordinary length. The adoption of drilled instead of punched holes for the rivets was particularly desirable, two plates being drilled together as they had to be rivetted, so as to ensure sound and good workmanship with the greatest strength; and having himself made from 120 to 150 boilers with drilled rivet holes, for working at pressures varying from 80 to 160 lbs. per square inch, he was satisfied that drilling was the only true and satisfactory system for manufacturing high pressure steam boilers of any class, and for ensuring good working boilers with uniform strength at the joints.

Mr. W. Richardson said they had five long boilers at Messrs. Platt's works at Oldham, 40 feet long by 5 feet diameter, fired underneath, made with punched rivet holes; and he had found the joints at the bottom were liable to crack between the rivet holes, partly from the iron having been strained by the punching, and partly because of the unequal expansion in such long boilers, the effect of which became of course concentrated at the weakest part. He had known these cracks extend to a length of even 2 feet along the line of rivets before any leakage began; but as soon as a leak was observed the men were instructed to open all the safety valves to let off the pressure, these boilers being heated by the waste heat from puddling and ball furnaces, so that the fires could not be hastily removed. The boilers were egg-ended working with 50 lbs. steam, and in order to prevent risk of the transverse joints parting across the bottom of the boiler, he had put in two long bars inside the bottom of the boiler, tying the ends together; and had also built a firebrick arch over the fire, extending back as far as the bridge, to protect the bottom of the boiler from the direct intense heat of the fire. Three cases had occurred where some of the bricks had become broken and had fallen out, and the plates though made of Low Moor iron and not left uncovered by the water became heated red hot and blown out so thin that the water broke through and put the fire out.

Mr. I. Smith enquired how the feed water was introduced in those long boilers.

Mr. W. Richardson replied that the feed water was supplied at the opposite end to the furnace, and was brought in at the bottom of the boiler.

Mr. I. Smith thought that mode of introducing the feed water was one of the causes why the plates had been found to crack along the lines of rivets at the bottom; for in some boilers 35 feet long at copper works in South Wales he had found that when the feed was sent in cold along the bottom of the boiler, or colder than the water in the boiler, the bottom plates became strained longitudinally by being exposed to the heat of the fire outside and the cool feed water inside; and a deposit of calcareous matter was also formed along the bottom, so that the plates were very liable to get burnt. The injurious effect of deposit was forcibly shown by holding a tin pot of water over a smith's fire, when the bottom could not be melted out, however thin; but if there were any sediment upon it, then it was burnt out directly. One of the long boilers of 35 feet length had now been reduced to 25 feet length and the firegrate proportionately diminished, and the same quantity of steam was found to be produced with considerably less consumption of fuel; new boilers had since been put down only 13 feet long and 6½ feet diameter with internal flues, and he thought it was a step in the wrong direction to prolong boilers to such lengths as had been mentioned. The feed also had been altered to enter only 4 inches below the water line, at the end furthest from the fire; and it was sent in horizontally so as to diffuse the water through the boiler and avoid an accumulation of deposit at one particular place. With this arrangement and heating the feed water before its entrance into the boiler they had never been troubled with burning a plate since the alteration was made.

The fuel used for these boilers was the semi-anthracite coal of South Wales, and a brick arch had formerly been put in over the fire to protect the boiler at that part from injury. But the boiler itself was now placed at a greater height above the firegrate; for a large space was needed for the proper combustion of the gases evolved from the fuel, and it was a mistake to suppose any loss of heat could arise from allowing too much room under the boiler; on the contrary, the furnace ought to be all one mass of flame under the boiler, without any smoke or soot, and he thought there was generally a loss of heat from setting the boiler too low, both in the South Wales and the South Staffordshire districts. The fire bridge too was usually brought up too close to the bottom of the boiler, which was a frequent cause of injury to the plates at that part by the severe impinging of the flame upon them; and he had found the area of passage at the bridge ought to be at least as much as 25 square inches per square foot of grate surface for the Staffordshire coals, according to the rule given by Murray. Attention had frequently been drawn to the importance of observing this requirement by the Manchester boiler association. Where boilers were heated by gas, as at the ironworks described in the paper, it was important to take care that the gas was burnt in the proper way under the boilers, by means of a number of burners distributing it over a large area, instead of being all burnt in a large mass at one spot. He was now erecting a furnace for generating gas to heat the boilers at his works in Birmingham, being satisfied of the advantages that would result from that mode of heating instead of ordinary coal fires.

Mr. W. Richardson said in the boilers he had described the water was not fed in cold, but was heated to 212° Fahr. before admission into the boiler. The mode of admitting the feed had also been altered, and it was now sent in through a rose pipe about 12 inches below the water line at the far end of the boiler, so that the deposit might take place as far as possible from the fire. The plates of the boilers were $\frac{1}{2}$ inch thick, in order to be strong enough to carry the pressure of 50 lbs. with safety; but that thickness was rather too great for a ready transmission of the heat. As to the liability of the plates to get burnt where covered with deposit, it was not only where the deposit was very thick that this risk was incurred; for with 3 feet depth of water over the plates he had known them burnt even with less than 1-16th inch thickness of deposit on them.

Mr. S. Bastow observed that the large majority of boiler explosions that took place occurred with the Cornish boilers with an internal flue, where any deficiency of water quickly left the top of the flue bare: and the plain cylindrical boiler was attended with much less risk of explosion, because the bottom plates exposed to the fire remained covered with water so long as there was any water at all in the boiler. If the bottom had to be strengthened by longitudinal tie bars, as had been mentioned, this showed he thought that there must be some defect in the working of the boiler or some improper impingement of the flame to cause so serious a strain upon the bottom plates. The Cornish boiler was no doubt more economical; but on account of its greater safety and simplicity he thought the long plain cylindrical boiler was better adapted for such situations as the ironworks described in the paper, where there was plenty of room for the boilers and fuel was cheap, or waste gas available from blast furnaces. He believed there were a large number of the plain cylindrical boilers longer than 73 feet; they were suspended by overhead bearers in the manner shown in the drawing, so as to be quite free for expansion and contraction without injury to the brickwork. These long boilers he had no doubt would continue in general use for such situations, as there were no other boilers so economical in construction, so durable in work, or so little liable to explosion.

Mr. F. J. **Bramwell** remarked that boilers heated by the waste gas from blast furnaces might certainly be expected to have an advantage in durability over similar boilers worked with ordinary coal fires; for it had been observed in Mr. Siemens' regenerative gas furnaces that the gas took an appreciable length of time to become sufficiently mixed with air for its complete combustion, and consequently the combustion was not confined to one place under the boiler, but there was a gentle combustion all over the bottom of the boiler, which must be highly conducive to its durability.

Mr. D. **Adamson** said he had had a large number of Cornish boilers under his observation and had never had any accident with them, although if the feed water were introduced in an improper manner the plates might unquestionably become burnt and the joints strained. But the plain cylindrical boiler he considered wasteful in fuel, and on that account inapplicable for many purposes, since the evaporative duty was never above 6½ lbs. of water per lb. of coal: whereas a good Cornish or tubular boiler, with proper room left for the circulation of the water, evaporated from 10 to even 12 lbs. of water per lb. of coal. In the explosions that had occurred with Cornish boilers he believed it had generally been the outer shell which had first been rent asunder, instead of the internal flue first collapsing as was usually supposed; for a great source of destruction in such boilers was the inequality of temperature to which they were subjected in different parts, owing to defective circulation of the water or bad arrangement of the flues surrounding the boiler; and more injury arose from the bottom of the boiler being too cold than from the top of the internal flue being too hot. Hence many boilers under such conditions suffered much in getting up steam, and he knew of boilers worked continuously day and night throughout the week which had lasted much longer than similar boilers fired only one day in the week and thus doing a far less amount of work than those continuously in use. He therefore believed the Cornish boiler, when properly arranged in these respects, was both the safest and most economical construction of steam boiler.

The CHAIRMAN enquired what was the mode of admitting the gas for burning under the boilers, where the waste gas was brought down from the blast furnace.

Mr. SAMPSON LLOYD replied that at the Old Park Iron Works, Wednesbury, where the gas was taken off from an open-topped furnace in the manner described in the paper, the gas was simply turned into the fireplace of the boilers through a single opening a little before the end of the boiler, so that it might become sufficiently mixed with the atmospheric air. So far as could be seen, the gas was completely ignited and thoroughly consumed during its passage under the bottom and through the flues of the boiler.

The CHAIRMAN observed that, in reference to the enlargement of the tuyeres and the reduction of the pressure of blast, this had been proposed by Mr. Fairbairn as long ago as 1835, with the use of the fan blast for the purpose instead of a blowing cylinder. But as to the yield of the furnace being the same, whether it were worked at a pressure of 2½ lbs. per square inch or ½ lb., that certainly appeared contrary to the experience of the iron trade; and it would be necessary to learn in connexion with any such statement whether there was anything peculiar in the minerals employed or in the size and construction of the blast furnace where the lower pressure of blast was used. In the South Staffordshire district he understood it was generally thought impossible to get the blast sufficiently into the heart of the furnace unless a high pressure of blast was employed for the purpose. With regard to utilising the excess of gas produced from the blast furnaces beyond what was required for the boilers and hot-blast stoves, at some of the ironworks on the continent it had now been customary for many years to work a portion of the puddling and heating furnaces with the waste gas from the blast furnaces, on account of the fuel being much dearer there than in this country, so that it was necessary to economise the waste heat as much as possible. All such questions however must be solved by the experience of individual works or districts: the closed top that had been found successful for blast furnaces in the North of England would perhaps not be suitable for Staffordshire or South Wales, and in these districts it might be indispensable to leave the furnace top open for part of the gas to burn out.

He proposed a vote of thanks to Mr. Coulthard for his paper, which was passed.

A vote of thanks was moved and passed to the Chairman, the Local Committee, and the Honorary Local Secretary, Mr. William Stubbs, for the excellent arrangements they had made for the meeting of the Institution in Liverpool; and also to the Liverpool Town Council for their kindness in granting the use of St. George's Hall for the purposes of the meeting.

The Meeting then terminated. In the afternoon the Members were conveyed by special steamer, granted for the occasion by the Cunard Steam Ship Co. through the kindness of Mr. MacIver, to the Canada Dock, where they inspected the large dock gates, swing bridge, and capstans, with the hydraulic machinery employed for working them, and also the "Asia" and "Australasian" steam vessels lying in the dock. They afterwards visited Messrs. Laird's iron shipbuilding yard, the Woodside Landing Stage, the Birkenhead Float, and the Hydraulic Chain Testing Machine.

In the evening the Members and their friends dined together in St. George's Hall, in celebration of the meeting of the Institution in Liverpool.

On Thursday, 6th August, an Excursion of the Members took place to the Ravenhead Plate Glass Works at St. Helen's, the Kirkless Hall Coal and Iron Works near Wigan, and the Ince Hall Collieries near Wigan, where they were handsomely entertained by Messrs. Pearson and Knowles. On returning to Liverpool the Members visited St. George's Hall in the evening, to inspect the arrangements for the mechanical ventilation and warming of the building, which were shown in operation by Mr. Mackenzie.

On Friday, 7th August, an Excursion was made by the Members to the London and North Western Railway Locomotive Works and Rail Works at Crewe, where a number of Bessemer steel rails were rolled; and also to Parkside, where the Water Trough for filling locomotive tenders whilst running was shown in operation. The Members were handsomely entertained at the Crewe works by Mr. Ramsbottom; and on both days the Excursions were made by special train granted to the Members for the occasion by the kindness of the London and North Western Railway Company.

PROCEEDINGS.

5 November, 1863.

The General Meeting of the Members was held at the house of the Institution, Newhall Street, Birmingham, on Thursday, 5th November, 1863; Sampson Lloyd, Esq., in the Chair.

The Minutes of the last Meeting were read and confirmed.

The Chairman announced that the President, Vice-Presidents, and five Members of the Council in rotation, would go out of office in the ensuing year, according to the rules of the Institution; and that at the present meeting the Council and Officers were to be nominated for the election at the Annual Meeting.

The following Members were nominated by the meeting for the election at the Annual Meeting:—

PRESIDENT.

Robert Napier,	Glasgow.

VICE-PRESIDENTS.

(Six of the number to be elected.)

Charles F. Beyer,	Manchester.
William Clay,	Liverpool.
Edward A. Cowper,	London.
Thomas Hawksley,	London.
Robert Hawthorn,	Newcastle-on-Tyne.
Sampson Lloyd,	Wednesbury.
Henry Maudslay,	London.
John Ramsbottom,	Crewe.
C. William Siemens,	London.

COUNCIL.

(Five of the number to be elected.)

Alexander Allan,	Perth.
John Anderson,	Woolwich.
Peter D. Bennett,	Westbromwich.
Frederick J. Bramwell,	London.
Charles Cochrane,	Dudley.
Benjamin Fothergill,	London.
Thomas Greenwood,	Leeds.
James Kitson,	Leeds.
Walter May,	Birmingham.
John Vernon,	Liverpool.

The **Chairman** announced that the Ballot Lists had been opened by the Committee appointed for the purpose, and the following New Members were duly elected:—

MEMBERS.

John James Birckel,	Liverpool.
Julius Boeddinghaus,	Elberfeld, Prussia.
Robert Clayton,	Preston.
Alfred Davy,	Sheffield.
Joseph Hall,	Gratz, Styria.
Frank Holt,	Manchester.
Sturges Meek,	Manchester.
John Musgrave, Jun.,	Bolton.
Walter Montgomerie Neilson,	Glasgow.
Thomas J. Perry,	Bilston.
Samuel Rigby,	Warrington.
Henry Sharp,	Bolton.
William Ford Smith,	Manchester.
William Hugill Walker,	Sheffield.
William Wallace,	Liverpool.
John Charles Wilson,	London.
Francis Wise,	London.
Owen Wright,	Oldbury.

HONORARY MEMBERS.

John Fairbairn,	Leeds.
George Emmerson Forster,	Washington.
William Hackney,	Birmingham.
William Nichols,	Burton-on-Trent.
Arthur Rigg,	Chester.
Thomas R. Storey,	London.

The following paper was then read:—

DESCRIPTION OF THE CORNISH PUMPING ENGINE WITH WROUGHT IRON BEAM AND THE PIT WORK AT CLAY CROSS COLLIERY.

By Mr. WILLIAM HOWE, of Clay Cross.

At the commencement of the working of the Clay Cross Colliery the upper seams of coal were drained by the Clay Cross railway tunnel; but as the lower seams were sunk to and worked, the water could no longer run into the tunnel, and gradually increased in quantity until it became necessary first to put in pumps of small size worked by the winding engines then in use on the colliery, which were sufficient for draining the works for some years. Afterwards as the works extended further, one pump after another was added, until there were altogether six pumping stations, at two of which were independent pumping engines of 40 horse power each. The water still following to the dip of the measures, it was found that either more pumping power must be added in the same way that it had been increased from the commencement, by putting down more engines, or else a single large pumping engine must be erected to drain the whole of the works, which had extended to an area of several hundred acres and a depth of 420 feet. After much consideration it was determined to erect a single large pumping engine on the Cornish principle, to pump the whole of the water at one point of the colliery. When this was completed it at once threw out of use seven sets of pumps and engines requiring several enginemen to look after them; and saved much expense in repairs, which had been continually necessary at one or other of the several pumping stations.

In adopting this plan of pumping it had to be taken into consideration that the drainage of the whole colliery would be dependent on one engine alone, instead of on several independent engines distributed at various points of the works; but as the working of the minerals went on increasing, the water partially left the pumps at the upper part of the works and ran down to the lower level, necessitating increased pumping power at a greater depth. This led to the conclusion that a central pumping station would be the most effectual and convenient; and the general result of experience showed that the Cornish pumping engine was most to be relied on for pumping from a considerable depth, and when well constructed was least likely to require repairs. The result has completely carried out these anticipations, as the new engine has maintained the entire drainage of the colliery for the last three quarters of a year, and has proved itself completely satisfactory in requiring no repairs, and has effected a great saving in cost of enginemen and repairs as well as in fuel and stores. It has to be remarked also that the plan of having pumps in connexion with winding engines, as was previously the case, involved the disadvantage that the engines when winding were not so perfectly under control for starting or stopping at particular points when required, on account of being burdened with the irregular load of the pumps: there was also the objection of having to disconnect the ropes when it was required to run the engine for pumping alone. A rotary pumping engine is also exposed to the dangers that inevitably arise with a pump, from an obstruction getting under the suction clacks and causing the pump to miss its stroke; or from the pump being only partially filled with water, so that when the plunger meets the water at half stroke, or at any other point short of the top, the concussion produced is so great that some portion of the machinery must give way.

The new Engine, forming the subject of the present paper, is an ordinary Cornish pumping engine, erected by the Butterley Company; and is shown in Fig. 1, Plate 67, which is a side elevation of the engine and a section of the house. The cylinder A is 84 inches diameter with a stroke of 10 feet. The engine house is a substantial building, on a foundation of concrete 18 inches thick. The cylinder pillar B is built of large ashlar stones set on the concrete, and is 18¾ feet high and 10 feet thick, running the full width of the house and built into the side walls. A pair of heavy cast iron girders C C, shown black in section, run underneath the cylinder pillar and extend under the side walls of the house, the holding-down bolts of the cylinder passing through them. The beam wall D, which extends across the house and unites with the side walls, is also built of large ashlar stones up to the level of the cylinder pillar, and is 8 feet thick; on the top of this work a cast iron plate E is laid, 7 feet wide, extending nearly the full width of the engine house; the beam wall is then built up of brick to within 3¼ feet of the bedplate for the main plummer blocks to rest upon, and is then finished with two courses of ashlar stone. Eight large tie bolts pass down through the spring-beam boxes, the bedplate, and the plate E at the bottom of the brickwork, securing the whole in one solid mass. The rest of the engine house is built of brick with stone quoins.

The top nozzle F, Fig. 1, Plate 67, contains the regulating, steam, and equilibrium valves: the regulating and equilibrium valves are each 12 inches diameter, and the steam valve 14 inches. The bottom nozzle G contains the eduction valve, which is 18 inches diameter. All the valves are on the ordinary double-beat principle, of massive construction and made of gun-metal. The top and bottom nozzles are connected with two side pipes H, each 12 inches diameter, through which the steam passes from the top to the underside of the piston, forming a perfect equilibrium. The cylinder cover is double, having a false cover with a space between. The cylinder is not made with the steam-jacket usually employed in Cornish pumping engines, but it is covered with wood and dry hair felting; an air space of 5 inches is left between the outside of the cylinder and the first covering of rough 1 inch boards; outside of these is placed about 1 inch thickness of felt, and outside that a cleading of 2 inches thickness: the whole having sufficient non-conducting power to keep the engine house remarkably cool. The metal of the cylinder is 2¼ inches thick, with flanges in proportion well bracketed, and weighs upwards of 11 tons. The piston has metallic packing, two outer rings and one inner one, all of cast iron; eight springs are placed inside the inner ring, with pins and nuts for adjustment.

There are two plug rods I, Fig. 1, Plate 67, one carrying the tappet to shut the steam valve, which may be varied to work to any degree of expansion, and also a tappet to work the cataract J for opening the steam, eduction, and injection valves; the other rod carries the tappets to close the eduction, equilibrium, and injection valves, and also a tappet to work the cataract K for opening the equilibrium valve. Generally, it is believed, Cornish pumping engines have only one cataract J, to open the steam, eduction, and injection valves at the conclusion of the outdoor stroke; but in the present case the writer preferred having a second cataract K to open the equilibrium valve at the conclusion of the indoor stroke, so as to have a pause at each end of the stroke, before the opening of the equilibrium valve as well as before the admission of the steam, in order to allow ample time for the pump valves to close completely.

The air pump and condenser are placed within a cast iron cistern L, Fig. 1, Plate 67, 10¾ feet long, 7 feet wide, and 11½ feet deep, bolted down upon two cast iron girders placed on a heavy ashlar stone and brick foundation. The foot and delivery valves and also the bucket valve are composed of india-rubber discs, with brass grid faces, having a guard above to prevent them from rising too high. The air pump bucket is packed with hemp, as is generally the case in such engines; and the injection valve is fixed on one side of the condenser, inside the cistern. The injection pipe is a 4 inch pipe tapering to 3 inches diameter at the end, and is set pointing in such a direction as to throw the water against the side of the condenser, whereby it is distributed so as to meet the steam. The water in the condensing cistern is kept at a temperature of 50° Fahr., the temperature of the hot well being 113°.

The engine Beam M, Fig. 1, Plate 67, is of wrought iron, designed and made by the Butterley Company, and is shown in detail to a larger scale in Figs. 2 to 6, Plates 68 and 69. It is made of two wrought iron slabs M M, one on each side, each slab being rolled in one piece 2 inches thick throughout, 36½ feet long over all, 7 feet 1 inch deep in the middle and 3 feet 4 inches deep at the ends. Each slab weighs upwards of 7½ tons, and the total weight of the beam is about 33 tons. The two wrought iron slabs are stayed and bolted together by large cast iron distance pieces N N with broad flat ends, the holes being bored and the bolts turned for bolting the slabs to the ends of the distance pieces. There is also a strong cast iron centre piece O, bored for the main centre gudgeon to pass through, Fig. 4, and keyed upon the gudgeon. Each end of this centre piece is turned, and has a projecting boss P also turned; the two large wrought iron slabs are bored to fit these bosses, and cast iron washer plates also bored are put on outside; and the whole is securely bolted together with twelve bolts on each side, turned and fitted into holes bored to receive them. The beam is stiffened on the lower side by a wrought iron plate Q, 12 feet long and 1 inch thick, underneath the main centre, connecting the two wrought iron slabs, which are 4 feet 1½ inch clear apart; the plate Q is rivetted to the slabs by two heavy angle irons. The gudgeons, excepting the main centre, are turned and fitted into holes bored in the sides of the beam, as shown in Fig. 6, having a cast iron washer plate bolted on the slabs both outside and inside to give a longer bearing, the washer plates being bolted through the beam slabs with bolts turned and fitted accurately into bored holes. The gudgeons are rivetted over the outside washers, which are slightly countersunk for the purpose, and a key is put through before this is done to prevent the gudgeon from turning. The beam thus constructed is perfectly stiff, and no lateral vibration can be perceived; it is altogether a complete success.

The parallel motion R, Fig. 1, Plate 67, is placed inside the beam slabs M; it is of the ordinary construction, very substantial and got up bright. The crosshead is a massive block of wrought iron through which the piston rod passes loose; the rod is 8 inches diameter and is secured in the crosshead by two half rings of 1 inch larger diameter, fixed in a recess turned in the top of the rod, the hole in the crosshead being also bored out to 9 inches diameter for half the length from the top; so that, should the piston strike the bottom of the cylinder, the piston rod would slide up free through the crosshead.

The engine is always started with high pressure steam without a vacuum, the steam and eduction cataract J, Fig. 1, Plate 67, being secured by a pin so that the valve catches cannot be lifted by the cataract. The regulating valve is opened by the handwheel and screw; the eduction and injection valves are opened by the handle; and the steam valve is opened by placing the foot in the stirrup on the rod. The engine thus makes the indoor stroke, and after a few strokes a vacuum is produced, and the engine regulated to the proper length of stroke by the regulating valve. The cataract J is then released so that it may liberate the valve catches; and the engine then works the desired length of stroke so long as the steam in the boilers remains at about the same pressure. The cataracts J and K which are charged with water are of the ordinary description, having a working barrel with a ram in it, which is placed inside a small circular cistern; the working barrel has only one clack or valve, which opens inwards. The outlet for the water is through a small orifice, the opening of which is regulated by raising or lowering a plug by means of a screw and handle. The speed of the engine is thus regulated by lengthening or shortening the interval between each stroke, so that it may be worked from a minimum speed of only one stroke in three or four minutes up to a maximum speed of about eight strokes per minute. The engine does not regularly make the full stroke of 10 feet length, but averages about 9 feet 7 inches; and the speed seldom exceeds four strokes per minute, the piston in that case attaining an average speed of about 76 feet per minute. The usual speed of the piston during the indoor stroke is about 290 feet per minute, and the outdoor stroke occupies about double the time of the indoor stroke. The speed of the indoor stroke varies of course according to the degree of expansion: when the steam is admitted to the cylinder at a higher pressure and cut off at about two thirds of the stroke, the indoor stroke is completed in about 1½ seconds, or the piston travels at the rate of about 400 feet per minute. But when this is the case the concussion of the pump rods in the shaft is so great that it is not desirable to work at such a high degree of expansion at present.

The boilers are of the plain cylindrical form with hemispherical ends, and fired underneath: they are four in number, each being 35 feet long and 5 feet diameter. The steam stop-valves are placed on a dome 4 feet high and 2½ feet diameter, rivetted on the top of each boiler; two horizontal steam receivers, each 13 feet long and 3 feet diameter, united by an expansion joint, form the main steam pipe, each passing over two boilers and connected with the boilers by elbow branches jointed on the stop-valve boxes: so that any condensation which may take place in the steam pipes between the boilers and the engine will run back into the boilers. It is intended to cover these steam receivers with dry hair felting and sheet iron, and also to place a house and roof over the boilers, in order to prevent radiation and condensation. The flues run from the fires up one side of the boilers and down the other side, being separated by a centre wall; and the flues of two boilers meet in one main flue leading to the chimney which is 101 feet high. The boilers are supplied with water from the hot well by a donkey engine.

The depth of the pit shaft is 418 feet, and the general arrangement of the pit work is shown in Figs. 7 and 8, Plates 70 and 71, which are vertical sections of the pit shaft with the pumps in elevation. The black portions represent the different seams of coal passed through in sinking.

A large stone 18 inches thick is bedded at the bottom of the shaft for the windbore of the bucket pump to rest upon. The remainder of the shaft bottom is filled in with hard burnt bricks and Barrow lime, forming a level bottom, so that the "sump" S, Figs. 7 and 8, may be cleaned as easily as possible when required. The bucket set of pumps, shown to a larger scale in Figs. 12 to 17, Plate 73, is 160 feet from the bottom of the windbore to the delivery pipe T, Figs. 7 and 10, the working barrel being 18 inches diameter and made for a 10 feet stroke. The pipes are 19 inches diameter, so that the bucket may easily be raised up through them if necessary. The bucket when at the top of the stroke is about 25 feet from the bottom of the windbore. The suction clack A, Fig. 13, is $10\frac{1}{2}$ feet from the bottom of the windbore, and is shown enlarged in Figs. 18 to 21, Plate 74: it is made of brass, with wrought iron lids faced with leather, shown black in Figs. 18 and 19, working on a pin B which acts as the hinge. The hole through which the hinge pin passes in the clack is slightly oblong vertically, as shown in Figs. 18 and 20, allowing the clack falls to lift vertically about 1-8th inch as they open. The hinge pin B is kept in its place by the clack door, and when the door is removed the pin can be drawn out and the clack lids changed in a few seconds.

The bucket, shown enlarged in Figs. 16 and 17, Plate 73, is made of brass, and the lids of iron faced with leather, like those of the clack; and the hole in the bucket rod through which the hinge pin B passes is also slightly oblong, to allow the lids to lift a little in opening; the pin is secured endways by a cotter, but should the cotter by any means slip out of its place, the hinge pin cannot get out, so long as the bucket is in the working barrel. The top part of the bucket is flanged out to fit the working barrel, and the hoop C at the bottom of the bucket also nearly fits the barrel. The leather, shown black in Fig. 16, is placed on the bucket in the usual manner, and covered by the hoop C below: by this means it is hoped to prevent the leather from wearing out on one side of the bucket, as sometimes occurs, by the flange on the top of the bucket and the hoop on the bottom keeping the bucket in a truly central position in the working barrel in this case, the leather acting solely as the water-tight joint between the flange on the top and the hoop on the bottom of the bucket.

The bucket spears are 9 inches square, fixed on the side of the main spears by strong wrought-iron clamps. They are made of pitch pine with butt joints, secured by four wrought iron strapping plates to each joint, the two side ones being 14 feet long and the other two 12 feet long: holes are bored in these strapping plates to a gauge, and the outside of the plates are faced down to form a true bearing for the nuts and bolt heads. The holes in the plates next the bolt heads are bored 1-16th inch larger in diameter than those next the nuts, in order to allow the bolts to be driven in easily until they are nearly up to the head, when they are driven tightly in; and the bolts also are turned to a gauge of 1-16th inch larger diameter for 1¼ inch length underneath the head, in order to get the full bearing through the hole in the plate. This mode of fixing gives an advantage also in getting the bolts out whenever repairs are required, because after they have once been moved they can then easily be driven out.

This bucket pump delivers into the drift D, Figs. 8 and 10, Plates 71 and 72, which is carried forward to the well E, whence the lower plunger pump F takes the water and delivers it at the drift near the top of the pit.

The lower plunger pump F, Figs. 7 and 8, Plates 70 and 71, is shown in section enlarged in Figs. 22 to 25, Plate 75. The clacks are of brass and fitted up the same as the clack already described in the bucket pump, as shown in Plate 74. The plunger G is 18 inches diameter, and the stuffing-box H of the plunger is fixed on the top of the cylinder so that it will admit of easy removal in case of wear or breakage. The rising main I is 19 inches diameter. This plunger pump forces the water about 270 feet from the bottom of the windbore in the well E, Figs. 7 and 10, to the delivery at the drift near the top of the shaft. The pump is carried on the substantial oak bunting J, which is 2 feet 8 inches square and 16 feet long, resting on a solid bearing of more than 4 feet length at each end, as seen in Fig. 10, leaving the middle unsupported part little more than 7 feet in length. The water raised by this plunger pump from the bucket pump below is not fit to be used for the boilers or condenser on account of its corrosive quality and the impurities it contains; it is therefore allowed to run away.

The upper plunger pump K, Figs. 7, 8, and 9, Plates 70, 71, and 72, is exactly the same in construction as the lower plunger pump, having the same size of plunger, 18 inches diameter; it pumps the water from an independent supply entering at the point L, which is 217 feet down the shaft. This water is collected in an extensive standage in an upper seam of coal shown black in the sections, Figs. 7 and 8; and being comparatively pure, so as not to injure the condensing apparatus or boilers, the whole of it is delivered into the condensing cistern, which is thereby kept at the temperature of 50°. It is then used for all the boilers at the lower part of the works, and also for the tuyeres at the blast furnaces. This water not being of a corrosive nature, cast iron clacks are used in the upper plunger pump, fitted exactly the same as the brass clacks already described in the two other pumps.

The pipes of the rising main of 19 inches internal diameter are cast in 9 feet lengths, as shown in Fig. 26, Plate 76, the thickness of metal varying from 1⅝ inch at the bottom of the rising main to 1 inch at the top of the pit, as shown in Figs. 26 and 27. The joints of the pipes are flanged joints, as shown enlarged to one quarter full size in the section, Fig. 29, and the end of each pipe is recessed 1 inch into the end of the next; the bearing faces O O are faced in the lathe, and between them is inserted a flat turned wrought iron ring, ¼ inch thick, wrapped round with tarred flannel, as shown black in Fig. 29. This is found to make a perfectly water-tight joint, the tarred flannel becoming squeezed up into the spigot and socket joint when the bolts are screwed up, as shown in Fig. 29. There are eight 1⅛ inch bolts to each joint, with a bracket 1½ inch thick cast between each bolt hole, as shown in the plan, Fig. 28; and the thickness of the flanges is the same at all the joints, as shown in Figs. 26 and 27, whatever the thickness of metal of the pipes themselves. In the whole of the pipes also the full thickness of metal, 1⅝ inch, is retained for a length of 7½ inches from the joint, to the ends of the brackets, as shown in Figs. 27 and 29.

The main pump spears, shown in the general vertical sections, Figs. 7 and 8, Plates 70 and 71, are made of pitch pine, the several lengths fitted together with butt joints in the same manner as the spears of the bucket pump already described; the joints being secured with four heavy wrought iron strapping plates, two of which are 18 feet long and the other two 16 feet long, all of them 7 inches wide and 2 inches thick in the middle, tapering to 1 inch thick at each end. The main spears are 16 inches square at the top and 15 inches square at the bottom; the five top lengths are each exactly 45 feet long, and the bottom length 50 feet long.

These spears work through heavy cast iron guides M, Figs. 30 to 32, Plate 77, which are supported on oak buntings 9 inches square resting on a cross bunting 12 inches deep by 10 inches wide, the latter serving also as a stay for the pumps. The part of the main spears which works through the cast iron guides is covered with hard wood liners or sliding pieces N about 1½ inch thick and planed up quite true and parallel, which may be easily replaced when worn. These spear guides are placed at the third, fourth, and sixth lengths of the spears, as seen in Figs. 7 and 8. There is no guide on the fifth length of spear, passing the upper plunger pump K, Figs. 7 and 8, as there is no room on the spear to place one there; but the two plunger pumps being fixed one on each side of the main spears are so nearly balanced that little or no vibration takes place at that point. The top spear leading from the end of the engine beam is guided by the banging beams P, Fig. 33, Plate 78, on the two sides only, the back and front being left open, Fig. 34, to allow of the vibration of the spears consequent upon the arc described by the extremity of the engine beam. The second spear from the top is guided all round by wood buntings and liners fixed on the spears, as shown at Q in Figs. 7 and 8, and to a larger scale in Figs. 35 and 36, Plate 78; the front liner being made hollow and the back one convex, Fig. 36, to allow of the proper amount of vibration of the spears, which is about 3½ inches at that point, as shown by the dotted centre lines in Fig. 36. In this view the spear is shown in the extreme position of vibration on one side of the vertical, being then at the bottom of its stroke.

There are two banging pieces R R, Figs. 33 and 34, Plate 78, clamped and bolted on each side of the main spears at the pit top, working down upon heavy oak buntings; and also two cast iron banging pieces S S, Figs. 30 and 31, Plate 77, about 130 feet down the shaft, which is as low as they can be placed. These are fixed by 2 inch bolts on the sides of the main spear, and work down upon two oak buntings 16 inches square, which rest at one end for about 2½ feet length in the shaft side, and at their outer ends on another oak bunting in front of the main spears, 4 feet 11 inches deep and 14 inches thick, going fully 3 feet into the shaft side at each end. These buntings with those at the top of the shaft form a secure resting place for the main spears when the engine is out of the house; and it is hoped they would be strong enough to stop the fall of the spears in case one of the clacks should ever break or any part of the pumps or rising main should burst. Figs. 30 to 34 show the spears at the bottom of the stroke, with the banging pieces R and S just clear of the banging beams. In ordinary working the equilibrium valve of the engine is shut at such a point that the banging pieces on the spears never touch the banging beams. The rising mains I of the pumps are stayed at every third pipe by wrought iron straps passing round the pipe and screwed through the buntings, as shown in Figs. 35 and 36, Plate 78, so that should a pipe require changing it would not be necessary to remove a single bunting; and the buntings are fixed so firmly in the shaft side that it would be rather a serious matter to remove one.

In Figs. 7, 8, and 11, Plates 70 to 72, is shown the recess U made in the shaft side for the purpose of packing and examining the glands of the plunger pumps F and K, so that the man may be entirely out of danger in the shaft. In Fig. 9 there is a recess for the suction pipe of the upper plunger pump K to pass through to the well L, and in Fig. 10 a similar recess to the well E for the suction pipe of the lower plunger pump F; the suction pipe is scaffolded over, and forms a platform to stand upon out of the shaft for changing and examining the clacks, thus keeping the shaft quite clear for repairs when needed.

In the rising main of each of the plunger pumps is placed a 2 inch valve with a pipe leading back to the well from which the pump draws, for the purpose of regulating the supply of water to each pump. These valves are worked by rods from the surface, and there are three floats, one in each of the plunger pump wells and the third in the well S at the bottom of the shaft, Figs. 7 and 8, Plates 70 and 71. The tops of the float rods are in sight of the engineman, so that by means of the return valves part of the water can be allowed to run back into either of the plunger pump wells, in order to keep the water level always above the top of the windbore, whereby the pumps are kept fully supplied with water, and always, as it is termed, "working on the solid." From each of the plunger pump wells an overflow pipe V, Figs. 7 and 8, is taken, one 6 inches and the other 8 inches bore, to allow any irregularity of supply to run to the bottom of the shaft.

As the engine is single-acting, the moving pit work has to be heavy enough to balance not only the column of water in each of the two plunger pumps, but also the piston, parallel motion, plug rods, and all the work hanging on the beam inside the engine house. The moving pit work &c. on the outer end of the beam weighs a little more than 34 tons, and the weight of the two columns of water is about 24 tons, leaving a balance of more than 10 tons in excess upon the outer end of the beam to overcome the weight of the piston and the work on the inner end of the beam, which amounts to rather more than 7 tons, thereby leaving an excess of weight of about 3 tons to overcome the friction of the pit work, and to give the necessary speed of motion to the water in the rising mains.

This engine has purposely been made larger than is necessary for the present requirements of the colliery, in order to allow for considerable future extension of the workings without the need of again increasing the engine power for drainage. In consequence of the engine being thus too large at present for the work to be done, it does not yet admit of expansion being carried to any high degree; for the total mass set in motion by the engine amounts at present to only about 54 tons, taking the effective inertia of the beam as equal to 6 tons collected at the extremities; which is not sufficient to control the velocity of the stroke at starting within the limits that are safe for the pump work, unless the degree of expansion be very limited, so as to allow of a comparatively low initial pressure of steam.

The accompanying indicator diagrams, Figs. 37 to 40, Plate 79, show the working of the engine under different degrees of expansion. Fig. 37 shows the diagram obtained in an experiment in which the steam was cut off at 71 per cent. of the stroke, which is about the limit of expansion considered prudent for experiment, on account of the risk of damage to the pit work from the concussion produced at the beginning of each steam stroke by the sudden snatch of the engine upon the pump rods. Fig. 38 shows a lower degree of expansion, with the steam cut off at 82 per cent. of the stroke; and Fig. 39 shows the diagram obtained when the steam is cut off at 84 per cent. of the stroke, and Fig. 40 at 91 per cent., which is about the range of expansion used in regular working. The boiler pressure was 14 lbs. per square inch above the atmosphere, but throttled down to about 8 lbs. on admission to the cylinder. The boilers are not at present roofed over nor covered at the top, nor are the steam pipes from them coated in any way; and the construction of the boilers, plain egg-ended boilers with the flue underneath divided by a middle wall, giving only one return of the heat under the boiler, is not adapted for an economical consumption of fuel; the evaporative duty obtained is consequently only about 3½ to 4 lbs. of water per lb. of coal slack. Under these circumstances the duty at present attained by the engine amounts to only about 27 million lbs. raised 1 foot high by the consumption of 1 cwt. of slack.

Each of the two pumps delivers about 108 or 110 gallons of water at each stroke, according to the length of stroke allowed to the engine. The number of strokes the engine is making at the present time is 4 per minute for twelve hours, delivering about 52,000 gallons per hour, and the engine standing the other twelve hours. It has worked up to 7 or 8 strokes per minute for a very short time, and as slow as ¾ stroke per minute. The quantity of water in the colliery fluctuates a great deal, requiring a corresponding variation in the rate of working the engine: during the past summer about 1½ strokes per minute during the twelve hours cleared the colliery of water; but now it requires about 4 strokes per minute to drain the workings in the same time.

The **Chairman** observed that the paper now read contained a great deal of practical information, and gave very ample details of the construction and working of the large pumping engine. The adoption of the wrought iron engine beam was a feature of particular interest after the terrible accident that had occurred at the Hartley Colliery by the breaking of the large cast iron beam. In the wrought iron beam described in the paper the two massive slabs composing it were of such dimensions that it would not have been thought practicable a few years earlier to produce them at any ironworks. Now however that this had been so successfully accomplished in the Clay Cross beam, it would probably lead to the introduction of similar large wrought iron beams wherever there were any great strains to be borne, in order to prevent any risk of the recurrence of such a terrible catastrophe as that at Hartley.

Mr. F. J. **Bramwell** observed that in reference to the reasons for adopting the Cornish pumping engine for draining the colliery at Clay Cross, in preference to a rotary pumping engine, it had been mentioned that with the latter, if the pump should ever be only half filled with water from any defect of the valves, the plunger meeting the water at half stroke would produce a concussion so violent as to risk breaking some of the machinery. But he thought the same objection applied equally to the Cornish engine, as he did not see what there was to restrain the violence of the concussion except the water itself in the pump barrel. He enquired whether there was any special self-acting arrangement in connexion with the equilibrium valve for partially closing the valve and wiredrawing the steam in the event of the plunger missing its stroke or the first portion of its stroke.

Mr. **Howe** replied that there was no arrangement for closing the equilibrium valve in case of the engine ever going out of doors at an excessive speed; but the valve itself was of small area, and would thereby have some effect in checking though not entirely preventing too rapid an outdoor stroke. In crank pumping engines he had seen many serious breakages of the machinery in consequence of the plunger missing the first part of its stroke and then suddenly meeting the water in the pump; and in such engines the danger of injury from the concussion was heightened by the circumstance that the force of the concussion arose not merely from the momentum of the moving parts, but was further increased by the engine power, in consequence of the steam continuing to act in the cylinders, so that the plunger was driven down upon the water by the full power of the engine. In the Cornish engine on the other hand, while the concussion was no doubt equally severe as far as it arose from the momentum of the plunger and pump rods, it was not further augmented by any engine power, as the pump rods made the down stroke by their own weight alone, without any aid from the steam. Moreover as the liability of a valve to stick once during any period of time was in proportion to the number of times it had to open and shut in that time, there would be greater risk of such concussions in the pumps with a rotary pumping engine running quick than with a large Cornish engine making a smaller number of strokes.

Mr. F. J. **Bramwell** concurred in the greater risk of a valve sticking in a large number of short strokes as compared with a few long strokes, since of course the oftener it had to open, the greater was the risk of its sticking. But in other respects he did not see that the Cornish engine possessed the advantage which had been attributed to it over a rotary engine with crank and flywheel, and thought on the contrary the advantage was on the other side. In the Cornish engine there was certainly nothing else beyond the momentum of the pump rods and plunger to produce a concussion when the plunger met the water at half stroke; but then, in consequence of the massiveness and weight of those parts in a Cornish engine, their momentum was far in excess of that in a crank engine: and though in the latter engine the steam was continuing to exert its force in the cylinder during the stroke of the pump, yet the addition of the heavy flywheel completely controlled the speed of the engine, and prevented it from running off instantly if ever the pump missed the beginning of its stroke; whereas in the Cornish engine, as soon as the equilibrium valve was once opened, the engine immediately went off unrestrained in the outdoor stroke, without any provision for checking its motion in the event of an accident. He therefore thought the concussion produced by such an accident would be far greater in the Cornish engine than in a rotary pumping engine with crank and flywheel.

Mr. E. A. Cowper enquired what was the reason why double-beat valves were not employed in place of the clack valves in the pumps of the engine described in the paper. Double-beat valves were used he observed for the steam cylinder, and they were almost universally adopted in Cornish engines where it was desired to work the steam to a good degree of expansion.

Mr. Howe replied that the clack valves in the pumps had been adopted because they were so simple in construction, and because there were not such skilled mechanics to be had at collieries as at waterworks for keeping the valves of the pump work in order. The simple clack valves in the pumps had been found to work remarkably well, and stood the work well, as they had not been looked at now for ¾ year since the pumps were first started. The concussion produced by the valve lids closing was very slight, and scarcely perceptible except when the engine was worked at a high speed; it was most apparent at the end of the indoor stroke of the engine, when the suction valves in the pumps were closing previous to the down stroke of the plunger.

Mr. E. A. Cowper observed that such valves were certainly not suitable for any high speed of working, on account of the violent concussion they would then produce in closing; but in the engine now described the degree of expansion of the steam was so limited that he thought it could scarcely be regarded as a Cornish engine, but rather as an example of the early Boulton and Watt style of engine. In the present instance however there was probably no particular need for economy in the consumption of coal; and this seemed to be the case from the boilers being of the plain cylindrical form, instead of Cornish boilers with an internal flue.

Mr. J. Fernie believed the single-beat pump valves were generally adopted for collieries on account of the dirty water to be pumped, while the double-beat valves were confined to waterworks where the water was clear.

Mr. J. R. Warham said that was the case, and no doubt the double-beat valves were the best; but in collieries there was so much dirt and sand mixed with the water in the process of sinking, all of which had to pass through the pump valves, that double-beat valves would involve too much trouble and expense in keeping them in working order.

Mr. E. A. **Cowper** enquired whether a sufficient degree of vacuum was obtained in the condenser in regular work; he thought the vacuum would be produced more quickly and efficiently if the injection water were admitted in a thinner stream and more divided form, by means of a conical injection valve throwing a thin conical sheet of water violently against the sides of the condenser, so as to present a greater extent of cooling surface for condensing the steam rapidly.

Mr. **Howe** replied that at the usual working speed of not more than four strokes per minute the vacuum in the condenser was 13½ lbs.; but in running at a higher speed, about five strokes per minute, the injection was found rather deficient, and had therefore subsequently been increased. The injection opening was so placed as to throw the water against the opposite side of the condenser, in order to make the water splash and expose a greater surface to the steam.

The **Chairman** asked what had been the extra cost of the wrought iron engine beam as compared with a cast iron beam of the same size.

Mr. **Howe** replied that at the time of originally designing the engine it was intended to have a cast iron beam, but just then the Hartley accident occurred, and it was therefore determined to adopt a wrought iron beam; and the extra cost of the present wrought iron beam had been £480 above that of a cast iron beam for the same engine.

Mr. J. **Fernie** had had an opportunity of seeing the engine at work at Clay Cross Colliery, and had been greatly pleased with the excellent workmanship and ample strength of all its parts and the substantial nature of the pump gear. The great feature was certainly the large wrought iron beam, made of two very strong wrought iron slabs rolled solid throughout their entire length of 36 feet, and 7 feet wide in the centre. There had been other designs also for wrought iron engine beams since the Hartley accident, and he understood a large wrought iron beam was now being made at Wednesbury of thin plates rivetted together.

The **Chairman** said the wrought iron beam in process of construction at his own works at Wednesbury was being made of a number of plates rivetted together, simply as a cheaper mode of construction than the use of solid-rolled massive slabs of the large size required. The rivetted beam would of course not be so solid and not quite so strong for the same thickness as the solid-rolled beam at Clay Cross; but its strength might be made up to the required amount by adding a sufficient number of thicknesses of plates. The total length of the rivetted beam was 28 feet, and the depth in the centre 4 feet; it was composed of two slabs, each made up of three plates of ¾ inch thickness rivetted together, making a total thickness of 2¼ inches for each slab. He enquired what had been the total cost of the Clay Cross pumping engine without the boilers or pumps.

Mr. **Howe** replied the total cost of the engine alone, including the wrought iron beam, but without the boilers, engine house, or pumps, was £3130; and including the boilers, engine house, and chimney, the total cost was under £5000. The pumps and pump rods cost about £2500 extra.

The **Chairman** asked how the joints of the rising main in the pumps were found to stand in work; and what means was provided for descending the pump shaft to examine the valves and pack the glands.

Mr. **Howe** replied that he had found the whole of the joints of the rising main stood perfectly water-tight in work; the construction of the joints was very simple, having merely the turned wrought iron ring wrapped round with tarred flannel inserted between the turned bearing faces of the joint. For examining the valves and packing the glands a small separate winding engine was provided, for ascending and descending the shaft by means of a bucket, independent of the pumping engine.

Mr. J. **Fernie** exhibited a new construction of indicator of American invention (Richards'), with which he had taken the diagrams from the Clay Cross engine. It had a much shorter stroke than the ordinary indicator, with a proportionately stronger spring, and the motion was multiplied by the long arm of a very light lever carrying the pencil, which was made to move in a straight line by means of a light parallel motion; the movement of the pencil was more steady and free from jumping, in consequence of the diminution of speed of piston from the shortness of stroke and the greater strength of the spring, and the figures obtained showed a very clear and steady line.

Mr. E. A. **Cowper** had no doubt such an indicator would work steadily; he had many years ago designed such a one, and Mr. Gooch made one on the same principle, with which steady diagrams had been obtained from locomotives on the Great Western Railway running up to a speed of more than 60 miles an hour.

Mr. F. W. **Webb** said he had used the Richards' indicator for taking diagrams from the "Lady of the Lake" outside cylinder express locomotive on the London and North Western Railway, the engine shown in the International Exhibition of 1862; and the diagrams obtained with it were perfectly steady up to 65 miles an hour. By having a second barrel for the paper, so as to change the paper quickly, as many as three dozen diagrams had been taken with the indicator from that engine in 40 minutes time, in running the 25 miles from Crewe to Stafford.

The **Chairman** proposed a vote of thanks to Mr. Howe for his paper, which was passed.

The following paper was then read:—

ON THE PROCESSES AND MECHANICAL APPLIANCES IN THE MANUFACTURE OF POLISHED SHEET GLASS.

By Mr. RICHARD PILKINGTON, Jun., of St. Helen's.

The manufacture of British Sheet Glass was introduced into England about the year 1832 by Messrs. Chance Brothers of Birmingham. Since then it has become generally used, having almost superseded crown glass, in consequence of the comparative ease of obtaining the large squares at present required for windows, and the absence of wave lines by which the vision is so much distorted in crown glass. The average size of sheet glass is 40 inches by 30 inches, but if required it can be made much larger; whilst with crown glass it is almost impossible to procure a square as large as 34 inches by 22 inches. Sheet glass when used for windows has generally a peculiar appearance when viewed from the outside of a building, on account of the unevenness of its surface, an eyesore partially obviated by the improved method of flattening, but entirely removed when the glass is polished. When polished it is known by the name of patent plate, to distinguish it from British plate. This polished sheet plate has a decided preference over British plate, being harder and more difficult to scratch, besides taking a higher polish; it is also cheaper.

The manufacture of polished sheet glass consists of the three following processes:—1st, melting and blowing; 2nd, flattening; and 3rd, polishing.

1. *Melting and Blowing.*—Two furnaces are required, one for melting the materials or "frit," and the other for reheating the metal whilst blowing it into a cylindrical form. The melting furnace is a reverberatory furnace, arranged for maintaining a high temperature with great uniformity and freedom from dust or other impurities arising from the fuel. The furnace, an eight-pot one, is

shown in Figs. 1 and 2, Plate 80. There are four "gathering holes" or "working holes" A A on each side of the furnace, as shown in the side elevation Fig. 2, each of the eight pots B having a working hole. The temporary brickwork C beneath each working hole can be removed when required, either to turn a pot or whilst fixing a new one. A raised bed D extends the entire length of the furnace, upon which the pots are placed on each side of the firegrate. The firegrate E extends the entire length of the furnace, with the exception of a space of about 4 feet length, and is fed from each end of the furnace. The air is supplied through the underground passage F entering from the open air; and by means of closely fitting doors the draught is regulated with great nicety.

Formerly it was considered necessary to use stone for the melting furnaces, but at the present time large bricks made of best fireclay have a decided preference. These firebricks vary in weight from a few lbs. to several cwts.; they are all made in moulds, dried, partially burnt, accurately dressed to templates, and built into the furnace, the whole being firmly secured by cast and wrought iron binders, as shown in Figs. 1 and 2, Plate 80. A small fire is lighted upon the firegrate and gradually increased, first to dry the furnace and afterwards to bake it: great care and attention are given to this operation, for upon it depends the duration of the furnace. After being baked, the furnace receives its number of pots, generally four or five on each side of the firegrate, in all eight or ten pots.

The manufacture of these pots is a matter of special importance, and they are made of the very best Stourbridge fireclay, which when thoroughly tempered is formed into rolls of about 1 lb. weight each, and worked layer upon layer into a solid mass, free from cavities containing air, and making a pot of about 4 feet height inside, 5 feet diameter at top and about 4½ feet diameter at bottom inside, weighing when dried about 25 cwts., and containing about 22 cwts. of melted metal. Great care is requisite to prevent any particles of foreign matter or dirt from getting into the clay; for if that were to happen the pot would not last its time, but would most likely give way when first heated to the working temperature. The average duration of a pot is about eight weeks, and their estimated value about £9 each. After being made, a pot remains in the same room for a year, the temperature being maintained at 60° Fahr., and it is then removed to a warmer room, where it remains in a temperature of 90° until it is wanted. When required for use it is taken to the "pot arch" to be baked, where the heat is gradually increased to that of the melting furnace, to which it is conveyed whilst red-hot as quickly as possible by means of a carriage or a crowbar on wheels, and placed on one side of the firegrate: this operation is repeated until all the pots are fixed in the melting furnace. The furnace ends are now closed, with the exception of the firehole at each end. A small portion of "cullet" or broken glass is put into each pot, and when melted is ladled so as to run down over the interior surface of each pot, after which the heat is increased for a short time. The pots are thereby glazed and are now ready to receive the material to be melted.

The quantity of raw material or "frit" allotted to each pot is filled into it in three or four charges, allowing a sufficient interval of time to elapse between each charge to ensure the previous one being melted. About sixteen hours of intense heat are required to melt the entire quantity, during which time the fluid metal boils violently, and before it can be worked requires cooling, which takes about eight hours. Whilst cooling, the small bubbles of air arising from the boiling of the metal ascend and pass away, leaving the metal clear, excepting the surface which is coated with impurities from the frit, from the roof of the furnace, and from the dust of the fuel, all of which must be removed before commencing work. Inside each pot and floating upon the surface of the metal is an annular ring made of fireclay 2 inches thick, having an internal diameter of 18 inches; this inner space of 18 inches diameter is cleaned, instead of the entire surface of the metal, thereby saving both time and material. The cleaning or skimming is performed by means of a light iron rod, chisel pointed, which being warmed the metal adheres to it; and this process is repeated whenever any impurities are perceived upon the surface of the metal.

The surface of the melted metal being cleaned, the workman dips into it the blow-pipe, Fig. 3, Plate 81, having previously warmed the nose end of the pipe. Withdrawing 2 or 3 lbs. of the metal, he allows it to cool to a dull red, and then dips the pipe again; collecting by degrees in this way, as shown in Fig. 4, a sufficient quantity to produce a given sized sheet of glass, which on the average would weigh about 20 lbs. Then while cooling the pipe he continually turns it round, drawing it towards himself, and in so doing forces the metal beyond the nose end of the pipe by means of the forked rest in which the pipe revolves, as shown in Fig. 5, leaving as little metal as possible upon the pipe. The blower now takes the pipe and places the red-hot mass in a hollowed wooden block upon the ground, Fig. 6, keeping the pipe in a horizontal position whilst revolving it, thereby producing a solid cylindrical mass of metal. During this process his assistant allows a fine stream of cold water to run into the block from a sponge, keeping the wood from being burnt and giving a brilliant surface to the glass. He next raises the pipe to an angle of about 75°, and blows until he has produced a hollow pear-shaped mass, Fig. 7, with its largest diameter the same as that of the finished cylinder. During this operation his assistant keeps the block wet, and a second block is generally used when commencing the blowing.

The glass now requires reheating, which is done at a furnace built of ordinary brickwork in an oblong form, its dimensions being determined by the number of blowers intended to work at it, generally four five or six at each side. The ground at each side of this furnace is excavated to a depth of about 7 feet, a width of about 16 feet, and the same length as the furnace; and over each of these spaces four five or six wooden stages are erected at distances of about 2 feet apart. Having reheated the glass, the blower repeatedly blows to maintain the cylinder of equal diameter throughout, whilst lengthening it by swinging it backwards and forwards in the 2 feet space, and occasionally swinging it round over his head; until a cylindrical piece of glass is produced, Fig. 8, about 11 inches diameter and about 50 inches long, closed at one end and having the blow-pipe attached to the other end. The blower first opens the closed end as follows:, enclosing as much air as possible within the cylinder, and stopping the mouth-piece of the pipe with his hand, he exposes the end of the cylinder to the heat of the furnace, which whilst softening the glass at the end expands the contained air to such an extent that a small hole is burst in the glass, as in Fig. 9, Plate 82. This hole is flashed open by revolving the pipe quickly, and when flashed the end of the cylinder is withdrawn out of the furnace; and by keeping the pipe in a vertical position for a few seconds the metal cools sufficiently to keep its shape. The cylinder is then placed upon a wooden trestle, and by touching with a piece of cold iron the pear-shaped neck near the pipe nose at G in Fig. 9 a crack is formed, which is continued round the neck by gently striking the blow-pipe, and thus the pipe is released, as seen in Fig. 10.

The cylinder has now one end of full diameter, but the other is contracted to about 3 inches diameter, Fig. 10, Plate 82, and must therefore be cut off. This is accomplished as follows: the cylinder having become cold whilst remaining on the trestle, the workman collects a small portion of metal upon the end of an iron rod and draws it into a thread of glass about $\frac{1}{8}$ inch diameter by means of a pair of pinchers. This thread he passes round the body of the cylinder at H H in Fig. 10, and after it has remained on a few moments the pinchers dipped in cold water are applied to the heated part, and the sudden contraction causes the end to fly off with a sharp report, leaving the cylinder about 45 inches long and 11 inches diameter.

2. *Flattening.*—To produce a flat sheet of glass from the cylinder thus obtained forms the second process of the manufacture. The flattening is acomplished as follows. The end of the cylinder that was flashed being slightly contracted in diameter and the thickness of metal much reduced, it is first necessary to cut off about 2 inches length from that end: for this purpose the cylinder is supported in a vertical position by means of a cradle, as shown in Fig. 11, Plate 82, over a small horizontal table; the bottom edge of the cylinder is introduced between the jaws of the small cutting instrument I, and the moveable jaw carrying the cutting diamond is pressed by a spring against the interior surface of the cylinder;

then by gently pushing the instrument forwards round the cylinder, allowing it to run freely upon its wheels, the end of the cylinder is cut off perfectly true. The cylinder then requires splitting longitudinally, which is accomplished by placing it in a horizontal position in a wooden cradle, as shown in Fig. 12, and a diamond fixed in the cleft of a stick at J is drawn along inside the cylinder from end to end, guided by the straight edge K, a gentle pressure being exerted on the glass in opposite directions at the diamond cut to complete the splitting.

The cylinder is now taken to the flattening kiln, Fig. 13, Plate 83, which consists of two furnaces built together, the first L for flattening, and the other M for annealing, the former being maintained at a much higher temperature than the latter. A portion of the bottom of the flattening kiln L, slightly larger than the largest sheet of glass to be flattened, is supported upon a carriage N, which with the flattened sheet is made to travel into the annealing kiln M, this plan being a very great improvement over the old method of pushing the flattened sheet whilst in a soft state. The moveable bed N is either of clay or stone, and by careful work is made as true as possible; upon this a sheet of glass is first flattened and left there to flatten others upon, in order to obtain sheet glass with as true a surface as possible. The split cylinder to be flattened is gradually introduced into the flattening kiln, being placed first at O and then at P, and when sufficiently warmed is placed upon the glass bed N with its split side uppermost; the heat soon softens it, so that with a slight assistance from the workman it lies down nearly flat on the bed N, and the sheet is afterwards carefully rubbed as flat as possible with a piece of wood fixed to the end of an iron rod. The moveable bed N is now pushed forwards into the annealing kiln M, as shown by the dotted lines, and after placing another cylinder to warm at O and P the workman removes the flattened sheet from the carriage N by means of a tool like a fork, and places it upon a prepared part of the floor of the annealing kiln M, to stiffen previous to piling it. The carriage N is now returned to the flattening kiln L, and the flattening operation repeated till the carriage again appears in the annealing kiln M.

The previously flattened sheet is first piled on its end against one side of the kiln at R, and then the last flattened sheet is removed off the carriage N, and left to cool on the floor of the annealing kiln like the previous sheet. This flattening process is continued until the annealing kiln M is filled, when it is closed up and allowed to cool, generally from 24 to 36 hours, the time being regulated by the thickness of the glass. On the completion of the cooling, the kiln M is opened and the sheets of glass are taken to the warehouse, where they are sorted to suit various purposes, a very large portion being packed and sent away without undergoing any further process.

3. *Polishing.*—The sheets intended to be polished are now selected, and pass through the third process of the manufacture to produce Polished Sheet Plate. Two processes are necessary for this purpose, smoothing and polishing.

Smoothing consists in working two sheets of glass one upon the other by hand with emery and water between them, and as their surfaces become obscured finer and finer emery is used until the surfaces are smoothed free from all defects. The apparatus used consists of a wooden bench, one half of which is 6 inches higher than the other; upon the former is placed a slab of slate about 1⅛ inch thick, larger than the sheet of glass, having as true a surface as possible. Upon this slab a sheet of glass is laid, with a piece of wet calico between the surfaces of the glass and the slab; by exerting a gentle pressure upon the glass the air is expelled from between them, and the sheet of glass is consequently held down upon the slab by the whole atmospheric pressure upon its surface, which holds it so firmly that when the sheets have to be raised from the slab many are broken even by experienced workmen. The wet calico is used in this case instead of plaster of paris for bedding the sheet of glass upon the table. In consequence of the close adhesion caused by the atmospheric pressure when the surfaces of the two sheets of glass get so true as to become closely in contact, it is impossible to work two large sheets one upon the other with the finest emeries, and it therefore becomes necessary to perform the latter portion of the rubbing process with a small piece of glass, say about 10 inches by 5 inches, until the process is completed. Both sides of the sheet of glass having been smoothed in this manner, and after a careful examination found free from defect, the sheet is then handed over to the polishing machine.

The perfection of the smoothing process in entirely dependent upon the purity of the emery, and the perfect uniformity of the grain in each successive quality employed; and consequently a very perfect process of cleansing and sorting the emery is requisite. The ordinary ground emery contains, besides numerous degrees of fineness of grain, many impurities which must be removed, and the good emery must also be accurately sorted into portions varying in size of grain from coarse to the finest. For every degree of fineness a separating vessel or cylinder is required; and taking No. 1 as the coarsest quality, that cylinder is made the smallest in the series, No. 2 cylinder about twice the capacity of No. 1, and No. 3 twice the capacity of No. 2, and so on throughout the required number of cylinders. The emery sorting apparatus is shown in Fig. 14, Plate 83, and consists of the required number of cylinders fixed so that No. 1 cylinder is about 3 inches higher than No. 2, and No. 2 the same height above No. 3, and so on. The cylinders are made of copper, and inside each is fixed a copper funnel S, long enough to reach within 3 or 4 inches of the bottom of the cylinder; and in the bottom of the cylinder is a hole closed by a wooden plug or a valve T of about 3 or 4 inches diameter, which is held up by the rod and spring balance U. The action of the apparatus is as follows. A supply of water being maintained by the cistern V, a constant stream is delivered by means of the tap W into the funnel of No. 1 cylinder; the water descends through this funnel to the bottom and ascends through the annular space to the top of the cylinder, whence it is conveyed by the spout X and poured down the funnel of No. 2 cylinder, ascending in the annular space of No. 2 and passing by the spout to No. 3 funnel; this is repeated as often as there are cylinders, and from the last and largest cylinder the overflow is carried to a drain. When the stream of water is running through all the cylinders and also passing away at the overflow, the powdered emery to be cleansed and sorted is sprinkled into the funnel of No. 1 cylinder, and this is continued until enough has been fed to fill up to within ½ inch of the bottom of the funnel: No. 1 being the smallest cylinder, the current of water through it will be the fastest, and the grains of emery left behind in this cylinder will consequently be the coarsest. The feeding of the emery is then stopped for a short time, and the stream allowed to continue until the water is running quite clear into the funnel of No. 2 cylinder: the valve T at the bottom of No. 1 cylinder is now opened, allowing the emery and water to fall into a vessel placed beneath to receive it; and as soon as the stream of water is again running through all the cylinders and passing away at the overflow, more emery is again sprinkled into No. 1 funnel. The succeeding cylinders are emptied in the same way, as they respectively become filled with the finer sorts of emery. The beauty of this process is the simplicity of apparatus required and the certainty of always obtaining an exact repetition of the several degrees of fineness in the respective cylinders. It will be observed that, in consequence of the cylinders increasing successively in capacity, the current of water ascending in the annular spaces decreases in velocity in the same proportion: consequently the emery deposited in each successive cylinder increases in fineness over that deposited in the previous one.

For the final process of polishing the sheets of glass after smoothing, the machine used is the same as that described at a previous meeting for polishing plate glass, (see Proceedings Inst. M. E., 1863, page 213, and Figs. 4 and 5, Plate 59.) The polishing benches have two bars carrying the polishing blocks and working lengthways backwards and forwards over the table on which the sheet of glass is laid, which is made to travel alternately from side to side transversely to the bars. The polishing blocks are worked at about sixty double strokes per minute, and the bars carrying them are supported upon rollers at a height of 6 or 8 inches above the table. The moving table is worked similarly to the table of a planing machine, moving one way quicker than the other by a reversing motion similar to that of a planing machine bed. It is generally considered that to obtain a good polished surface the polishing blocks should not pass twice in succession over the same surface. Upon the moving table are fastened slabs made of a wooden frame covered with slates, upon which the sheets of glass to be polished are bedded in plaster of paris. After one side has been polished, the glass is taken up and relaid, and the other side polished. The polishing blocks are about 5 inches square, covered with felt and weighted with about 84 lbs. each. The red liquor used in polishing is red oxide of iron, obtained by burning sulphate of iron in a reverberatory furnace to a dark red when cold, and it is then ground in water to the finest grain possible. The cutting grain of this material is about the hardest and finest that can be produced, and well worth examination by the microscope.

Mr. **Pilkington** exhibited a series of specimens from the St. Helen's Crown Sheet and Plate Glass Works, illustrating the several stages of the manufacture and the materials employed.

The **Chairman** observed that the members had had an opportunity on the occasion of the Liverpool Meeting of seeing the manufacture of plate glass at the Ravenhead Works, and a paper on the subject had been read on that occasion; and the present paper gave a corresponding description of the manufacture of polished sheet glass.

Mr. P. **Rigby** observed that polished sheet glass was a very superior article to the crown glass of which it had taken the place, and required more care in the final polishing process in order to get both sides of the glass finished to the same degree of polish. Much depended upon the correct separation of the emery powder into proper gradations of fineness, which was effected by the successive cylinders in the emery washing apparatus being made in correctly adjusted progression as regarded their size. Great care was also needed in feeding the emery powder into the first funnel, so as not to go on feeding too long, otherwise some of the coarser particles would get carried over by the current of water into the next cylinder along with the finer sorts. The time of polishing the sheets of glass was generally required, in his own experience at Messrs. Chance's works, to be longer for the side first polished, because when the plate was turned over for polishing the second side, the first surface became slightly dulled by being laid in the plaster; and he enquired whether in the specimens exhibited of polished glass the time of polishing had been equal for both sides or longer for the first side.

Mr. PILKINGTON replied that it took about nine hours on an average to polish each side of a sheet of glass, but there was no fixed time for the process, the polishing being continued until the surface of the glass was brought up to the requisite brightness; and he had not found that it afterwards became dulled at all by being laid in plaster for polishing the other side, the plaster having no sensible effect on the brightness of the surface. Even in what was called the rough state however, before smoothing or polishing, sheet glass was quite equal in appearance to ordinary crown glass; while the finest and thinnest sort of polished glass, of which a sample was shown, was that made for the use of photographers and for framing fine engravings. The emery sorting apparatus was found in practice to divide the different sizes of emery with extreme accuracy into the respective cylinders, as was proved by examining with a microscope the several degrees of fineness.

Mr. J. E. CLIFT enquired whether the rubbers had to be removed at intervals during the polishing process, in order to examine the surface of the glass.

Mr. PILKINGTON replied that was not necessary, as the rubbers travelled far enough at each stroke to expose the whole surface to view, and the workman examined the degree of polish of the surface by holding a lighted candle near it while the glass was still lying on the slab of the machine. The process was stopped as soon as the glass appeared sufficiently polished.

Mr. F. J. BRAMWELL observed that if it were the fact that the surface of the glass became at all dulled by being laid in plaster, and if it were attempted to compensate for this by polishing the first side longer than the second, the result must be that both sides would be defective in polishing, the second side not being finished to a greater degree of polish than the first side would have after lying in the plaster. The smoothing and polishing processes here employed were indeed identical with those in the manufacture of plate glass; but the latter required a preliminary process of grinding, on account of the unevenness of its surface on leaving the annealing oven, whereas the blown sheet glass had its surface sufficiently even to allow of its being laid at once on the smoothing machine without having undergone grinding. The emery sorting apparatus was the same that was used in plate glass machinery, and he did not think a more perfect plan could be devised for separating the several degrees of fineness; the principle was the simplest possible, the different sized particles being accurately sorted according to the velocity of the current of water in the successive cylinders, just in the same manner as a river discharging itself into a lake deposited the heavier portions of its detritus at the entrance and carried the lighter matters further out into the body of the lake. A similar method had formerly been employed in the preparation of beaver for the manufacture of hats, the hairs being separated from the beaver by a current of wind just sufficient to float the beaver; this accordingly deposited the hairs at a near point but carried the beaver to a greater distance. In grinding the emery the old plan had been to grind it dry under edge runners, and as there was no provision for removing the particles as fast as they were ground, the consequence had been that some portions were over-ground and impeded the grinding action of the machine upon the portions that still required grinding: now however by grinding the emery wet, with a stream of water constantly carrying off the particles as soon as they were ground, the machine was kept continually cleared and was enabled to grind in two days as much emery as it had previously ground in six. The principle of the stream of water was the same as that of the air blast used in millstones to remove the flour from between them, and in the American rice-husking machines for blowing away the husk of the rice grains as soon as it was broken up fine enough to be so removed.

The CHAIRMAN enquired whether any improved mode of laying and lifting the plates of glass on the machines had been devised, in order to diminish the risk of breaking the glass; he thought there seemed room for improvement in that respect, for at present the loss by breakage of the glass in handling was very great.

Mr. **Pilkington** was not aware of any improvement having been made in that respect, though it was certainly much needed.

Mr. E. A. **Cowper** observed that for smoothing the sheets of glass, instead of the process being performed by hand as described in the paper, a machine was employed at Messrs. Chance's works, in which the smoothing action was produced by a link motion like the parallel motion of beam engines, the upper sheet of glass not working right round upon the lower, but passing over it in a curvilinear course with a figure of 8 movement. The melting furnace shown in the drawing appeared to be the ordinary form of furnace used for glass melting, previous to the introduction of Mr. Siemens' regenerative gas furnace. In the construction of the old furnace one practical difficulty arose from the "tears" or droppings of dirt from the brickwork forming the roof of the furnace, which dropped into the glass melting pots and damaged the glass; this was now obviated by setting the lower rows of bricks each a little in advance of the upper, so as to present a slight step inside the furnace, which prevented the "tears" from dropping and caused them to run down the sides of the furnace instead. The use of a current of air for separating fine substances, to which reference had been made; was also adopted in the process of grinding sulphur for vulcanising purposes, the sulphur being ground down to the condition of an impalpable powder which was carried away by the air into a proper receptable.

Mr. P. **Rigby** remarked that the smoothing machine used at Messrs. Chance's works had been adopted for giving the smoothness of polished plate glass to sheet glass, as that was now required for many purposes and particularly by photographers; but hand smoothing never made the surface quite so smooth and uniform as was done by the machine.

The **Chairman** proposed a vote of thanks to Mr. Pilkington for his paper, which was passed.

The Meeting then terminated.

INDIAN RAILWAY BRIDGE PIERS.

Fig. 2. Transverse Section.

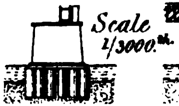


Fig. 1. General Elevation of Jumna Bridge (half length). Total length 3075 feet.

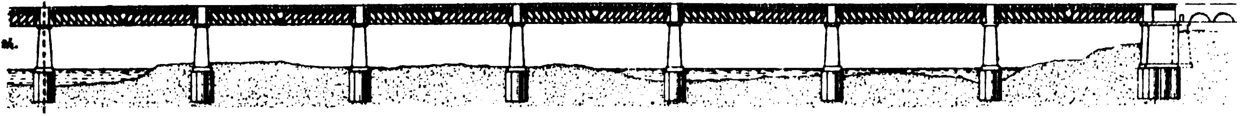
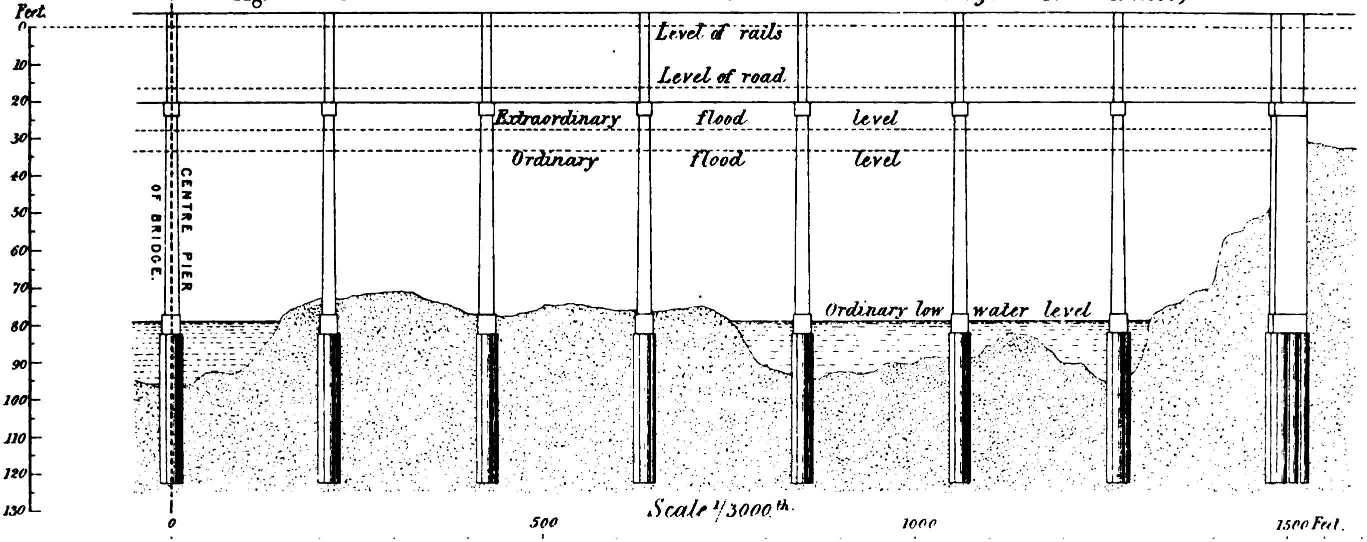
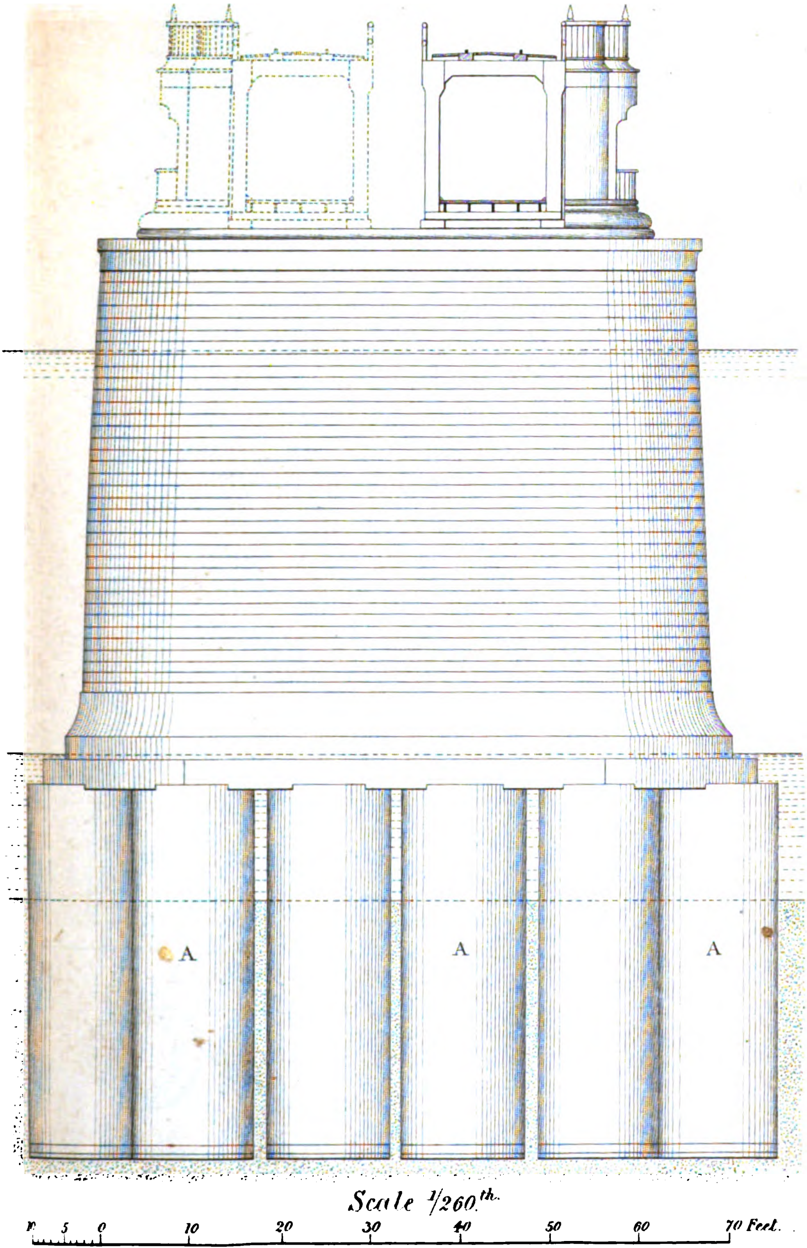


Fig. 3. Section of bed of river (vertical scale enlarged five times.)



INDIAN RAILWAY BRIDGE PIERS. *Plate 2.*

Fig. 4. *Elevation of Pier, taken transversely of the bridge.*



(*Proceedings Inst. M.E. 1863. Page 16.*)

INDIAN RAILWAY BRIDGE PIERS.

Plate 3.

Fig. 5. *Vertical Section of Pier, taken longitudinally of the bridge.*

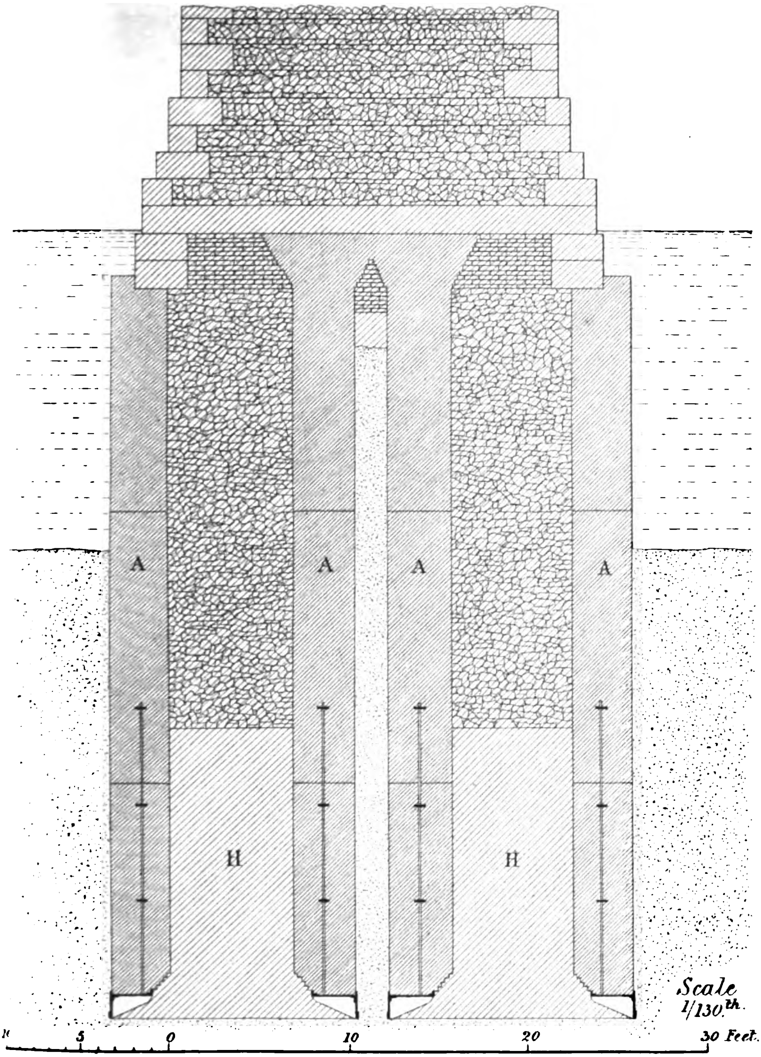
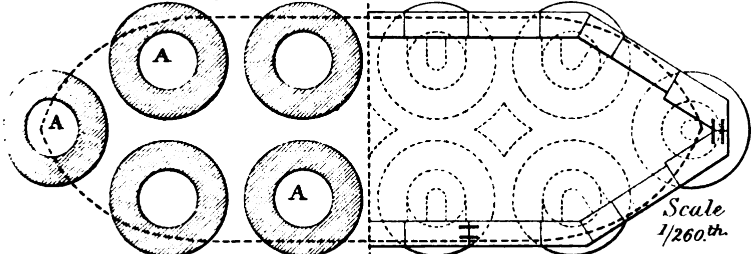
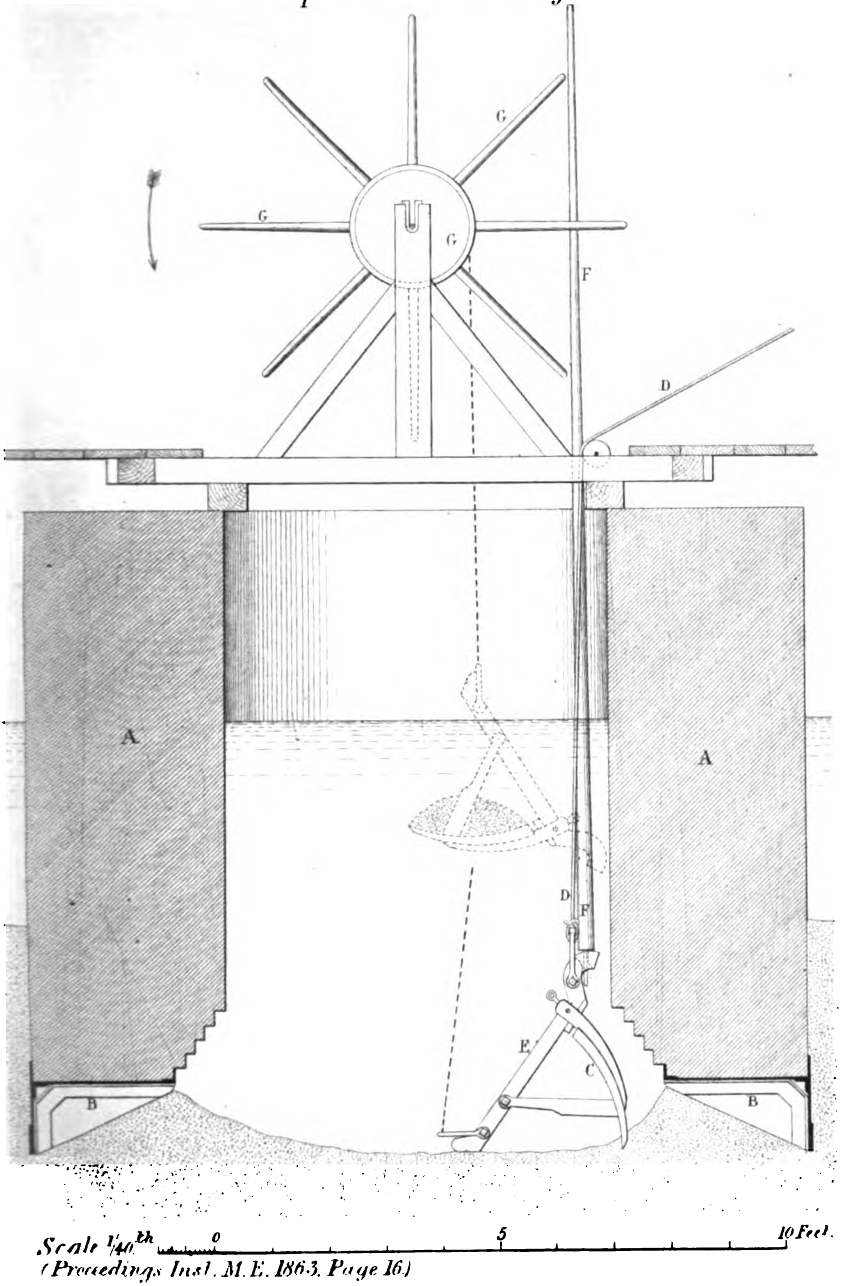


Fig.6. *Sectional Plan of Pier.*



(Proceedings Inst. M. E. 1863. Page 16)

Fig 7. *Vertical Section of Brick Cylinder in process of sinking.*



(Proceedings Inst. M. E. 1863. Page 16.)

INDIAN RAILWAY BRIDGE PIERS.

Plate 5.

Vertical Sections of Brick Cylinder, showing mode of excavating by the Scoop.

Fig. 8.

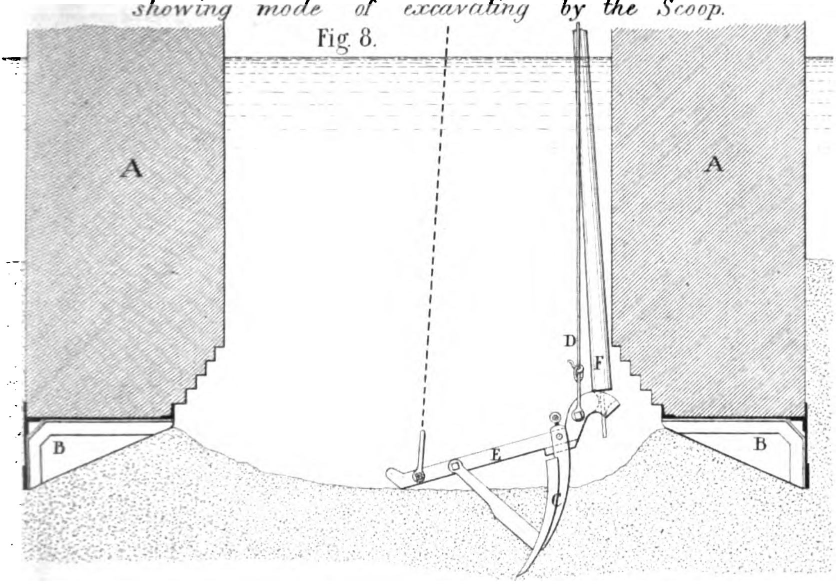


Fig. 9.

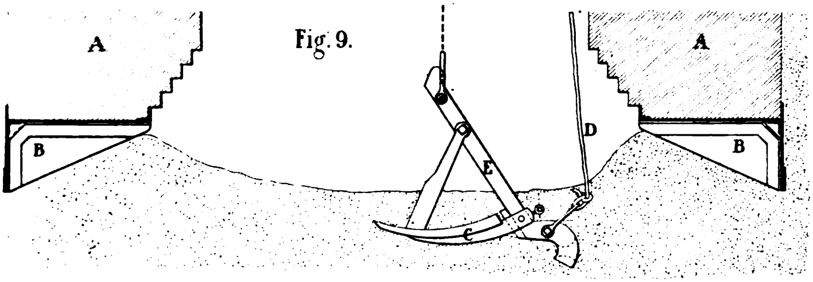
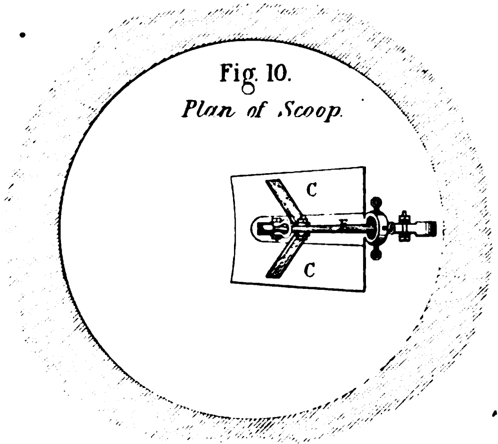


Fig. 10.

Plan of Scoop.



Scale 1/40th.

Ins 12 6 0 5 10 Feet.

(Proceedings Inst. M.E. 1863. Page 16.)

TYPE COMPOSING MACHINE. *Plate 6.*

Fig. 1. *Plan of Composing Machine.*

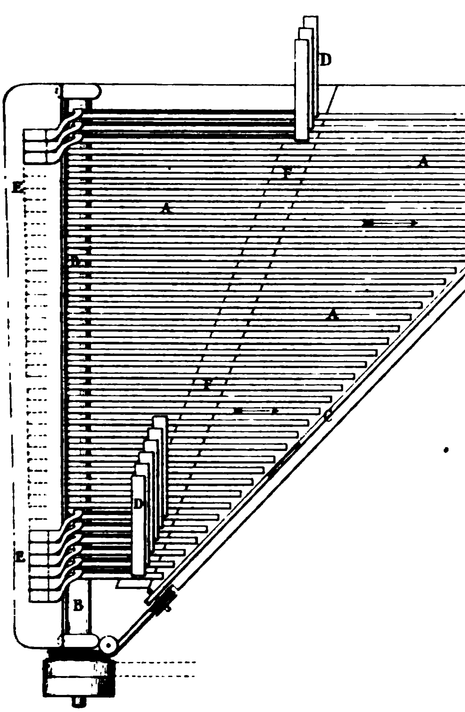


Fig. 2.

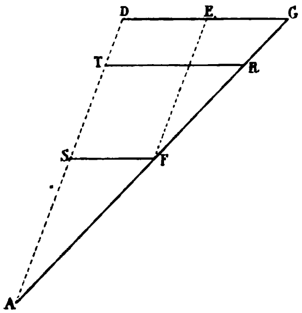
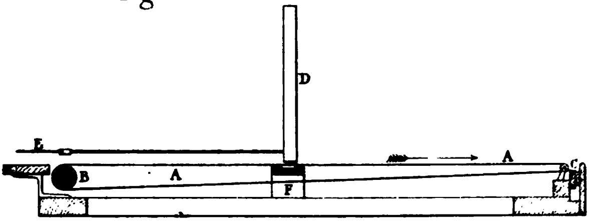


Fig. 3. *Sectional View.*



Scale 1/16th.

(Proceedings Inst. M.E. 1863. Page 34.)

TYPE COMPOSING MACHINE.

Plate 7.

Fig. 4. *Elevation of Key action.*

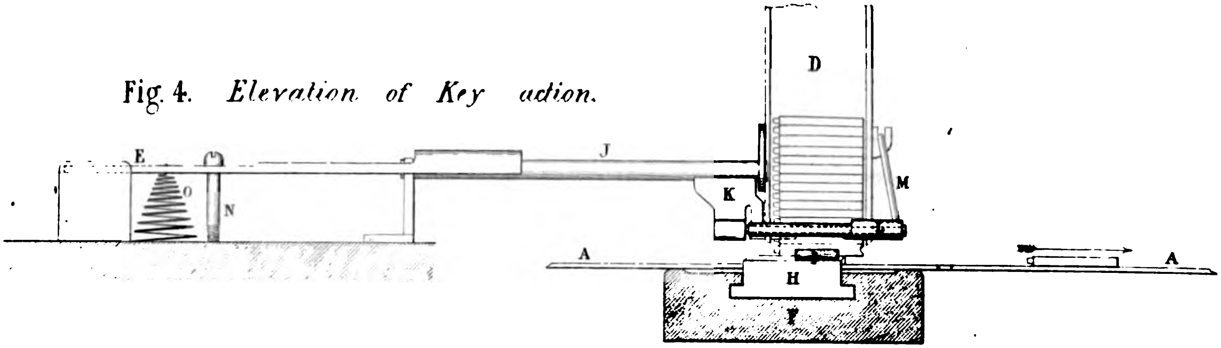
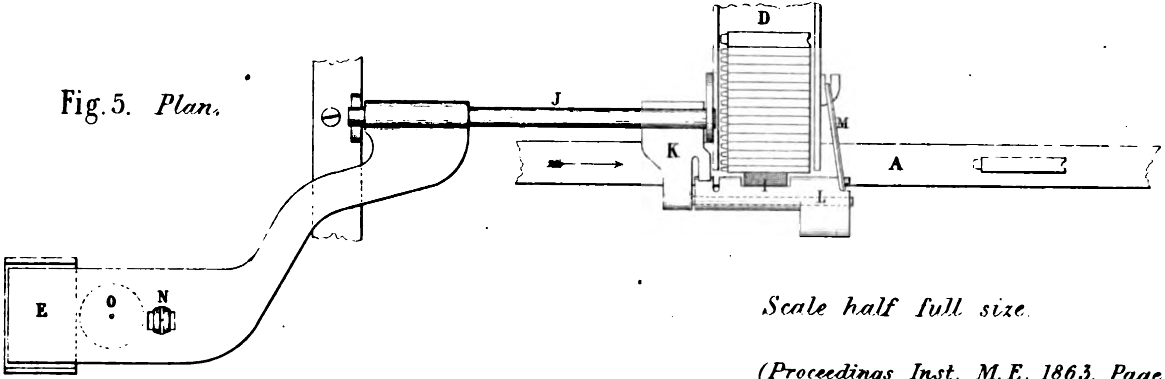


Fig. 5. *Plan.*



Scale half full size.

(Proceedings Inst. M.E. 1863. Page 34.)

TYPE COMPOSING MACHINE.

Fig. 7. Plan of Delivery of Types from parallel bands on to diagonal collecting band.

Scale half full size.

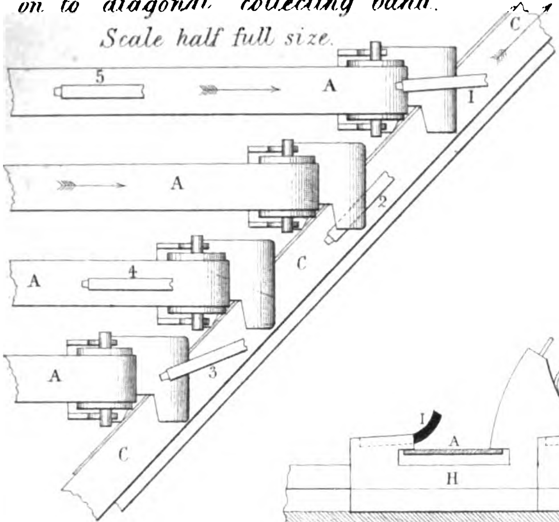
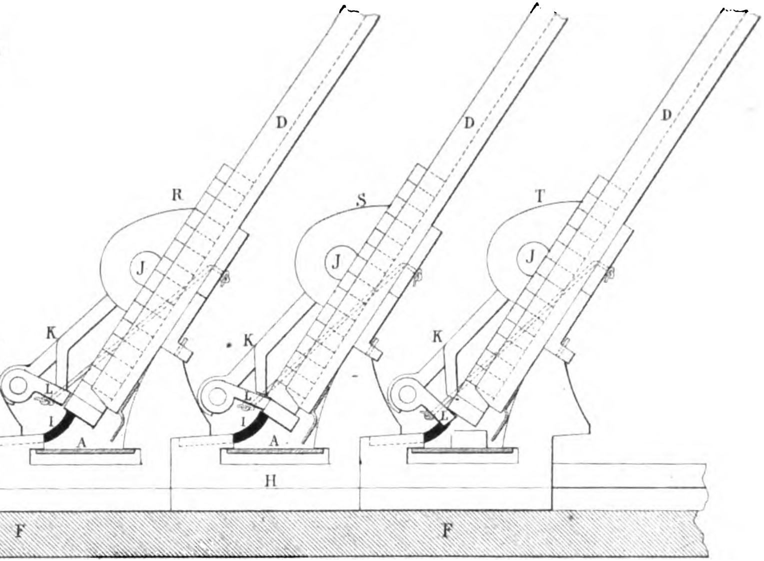


Fig. 6. End View of Key action.



Scale full size.

(Proceedings Inst. M. E. 1863. Page 34.)

TYPE COMPOSING MACHINE.

Plate 9.

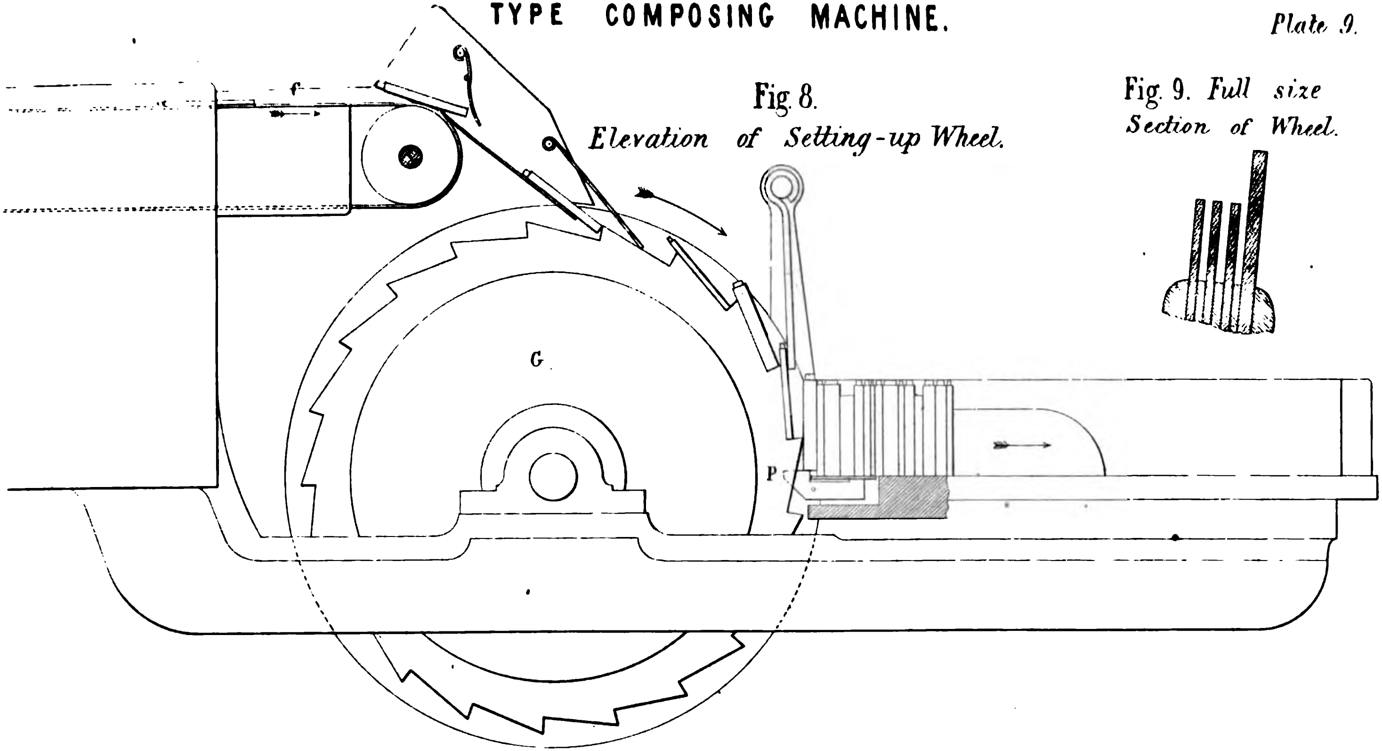


Fig. 8.
Elevation of Setting-up Wheel.

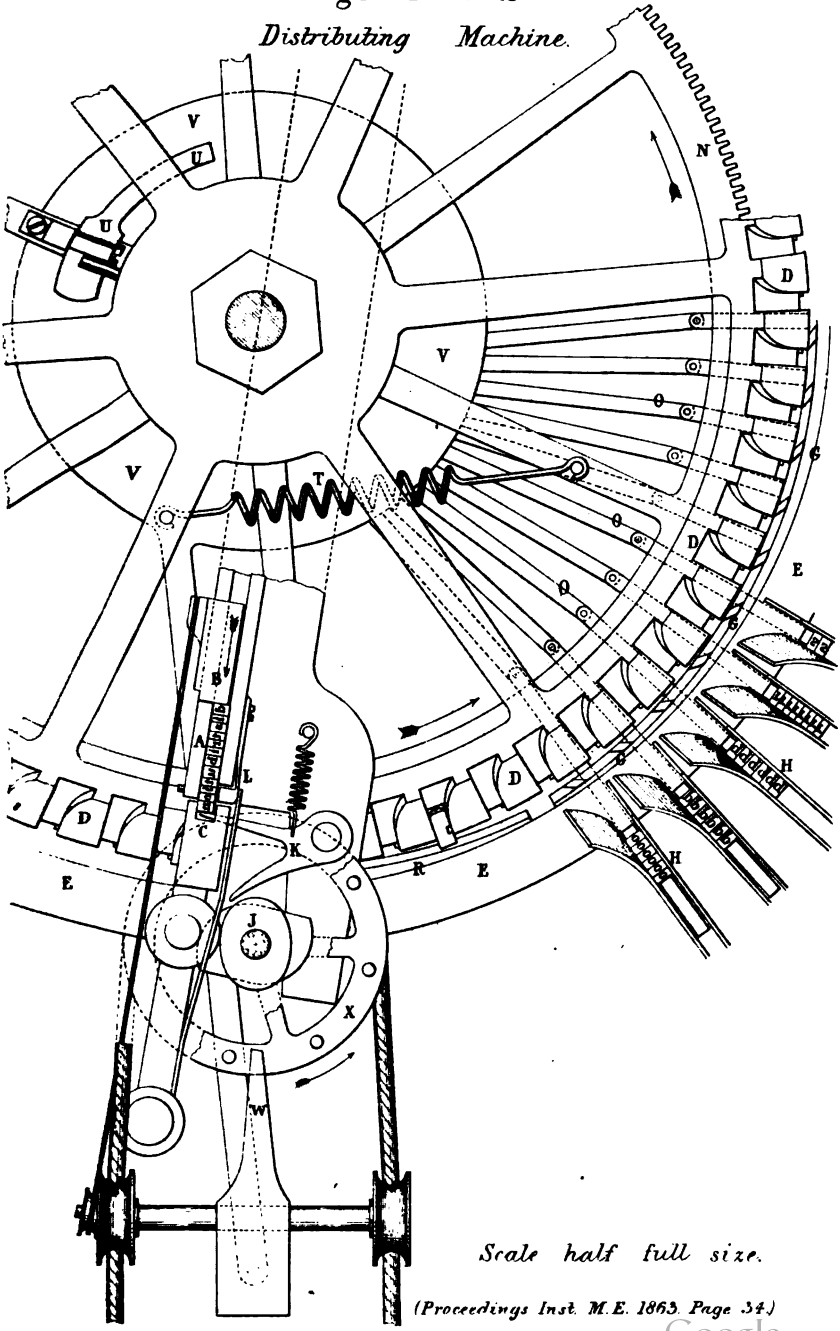
Fig. 9. *Full size*
Section of Wheel.

Scale half full size.

(Proceedings Inst. M.E. 1863. Page 34.)

TYPE DISTRIBUTING MACHINE. *Plate 10.*

Fig. 10. *Plan of Distributing Machine.*



Scale half full size.

(Proceedings Inst. M.E. 1863. Page 34.)

TYPE DISTRIBUTING MACHINE. *Plate 11.*

Stop Plate for cutting off only one type at a time.

Fig. 11.

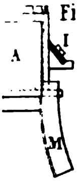


Fig. 12.

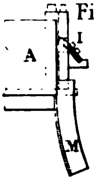


Fig. 13.

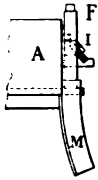
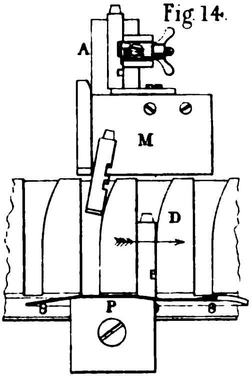


Fig. 14.



Scale half full size.

Vibrating Striker for cutting off types.

Fig. 15.

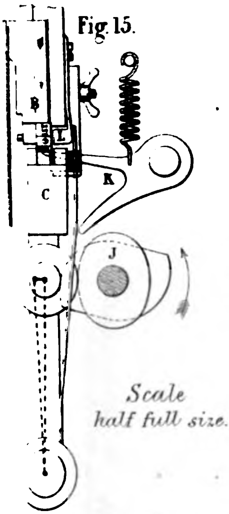
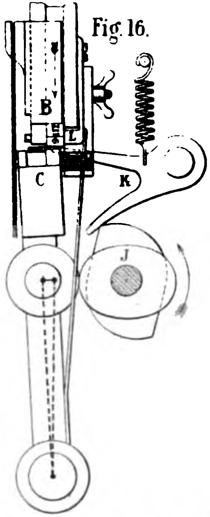


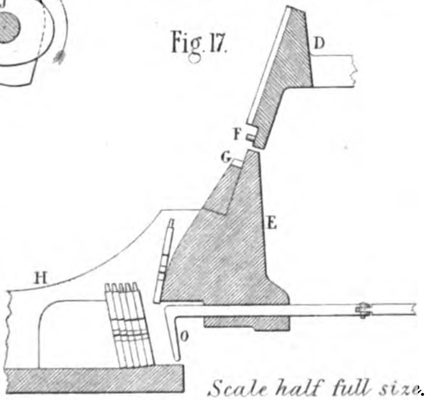
Fig. 16.



Scale half full size.

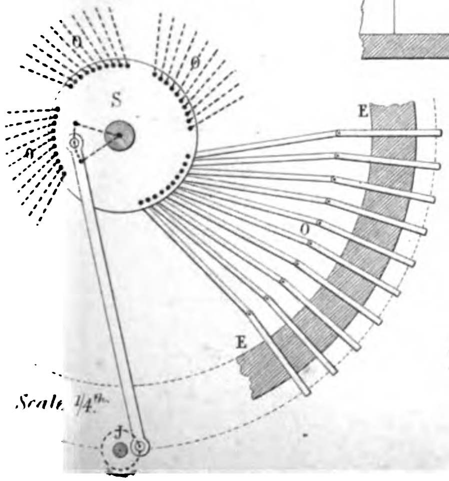
Type falling from Distributing Wheel.

Fig. 17.



Scale half full size.

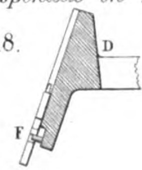
Fig. 20. *Pushing Motion of Type Drivers.*



Scale 1/4th.

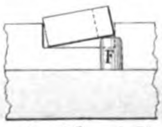
Type suspended on Pin.

Fig. 18.



End View of Type in Groove.

Fig. 19.



Scale double full size.

(Proceedings Inst. M.E. 1863. Page 34.)

TYPE DISTRIBUTING MACHINE.

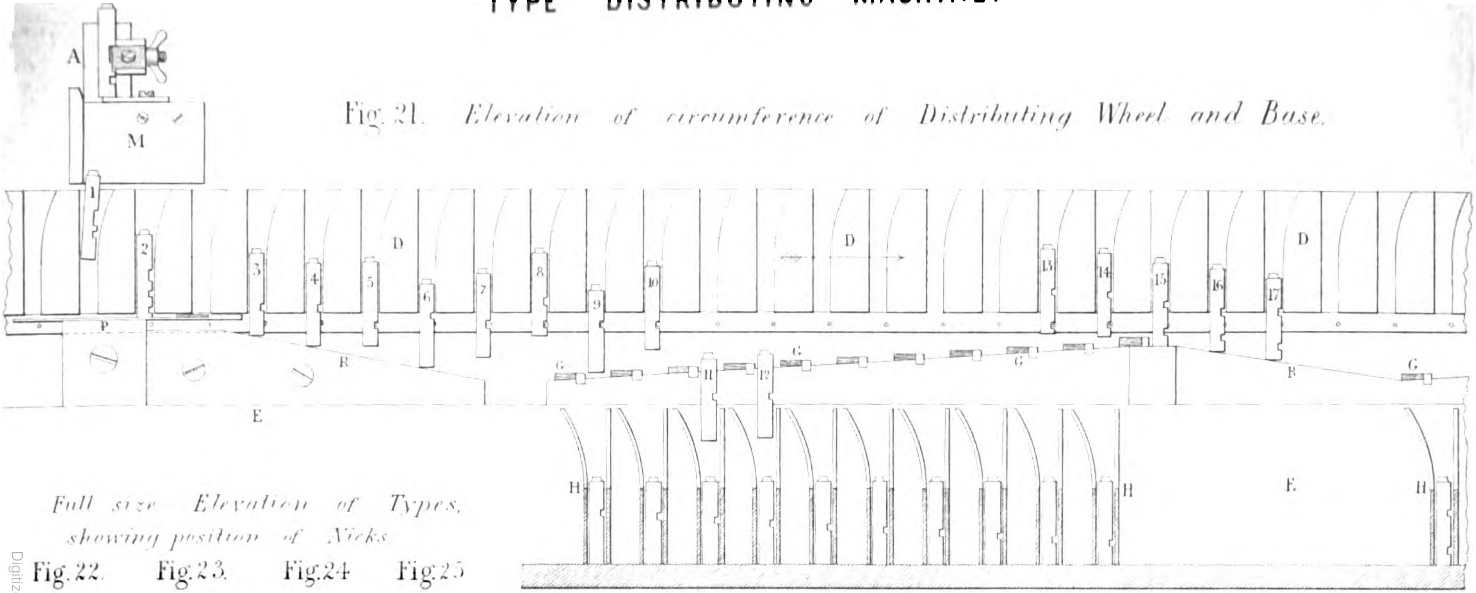


Fig. 21. *Elevation of circumference of Distributing Wheel and Base.*

Scale half full size.

Full size Elevation of Types, showing position of Nicks.

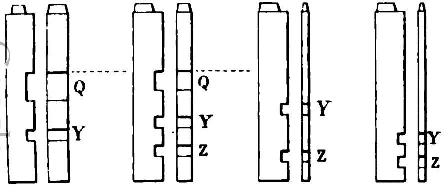


Fig. 22. Fig. 23. Fig. 24. Fig. 25.

(Proceedings Inst. M.E. 1863. Page 34.)

COTTON DRAWING ROLLERS.

Plate 14.

Fig 5. *Drawing Frame.*

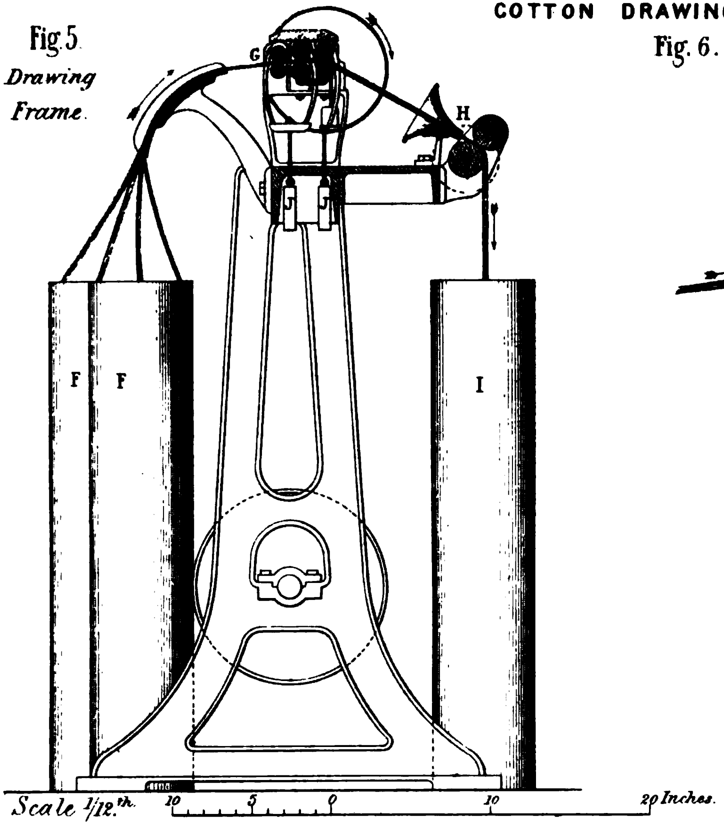
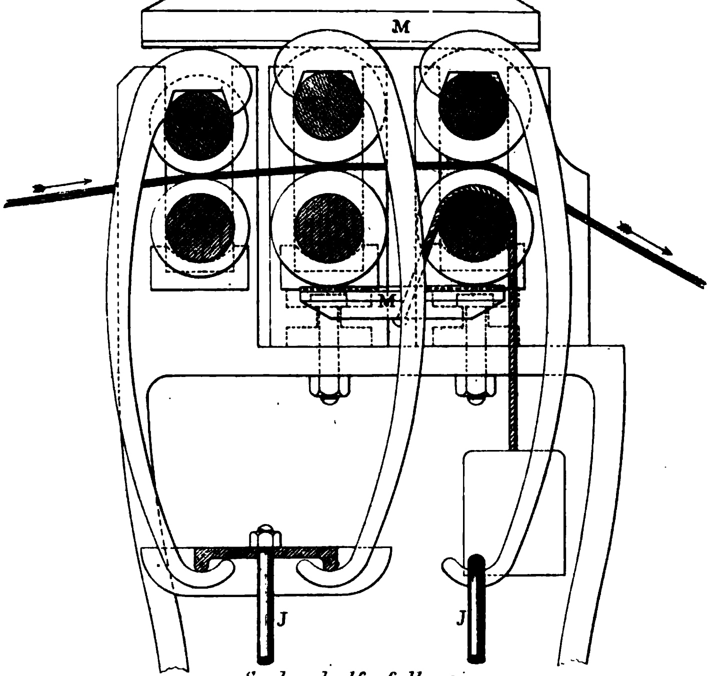


Fig. 6. *Transverse Section through centre of Drawing Rollers*



Scale half full size

(Proceedings Inst. M. E. 1863. Page 59.)

COTTON DRAWING ROLLERS.

Plate 15.

Fig. 7. *Longitudinal View of improved Drawing Rollers.* *Scale half full size.*

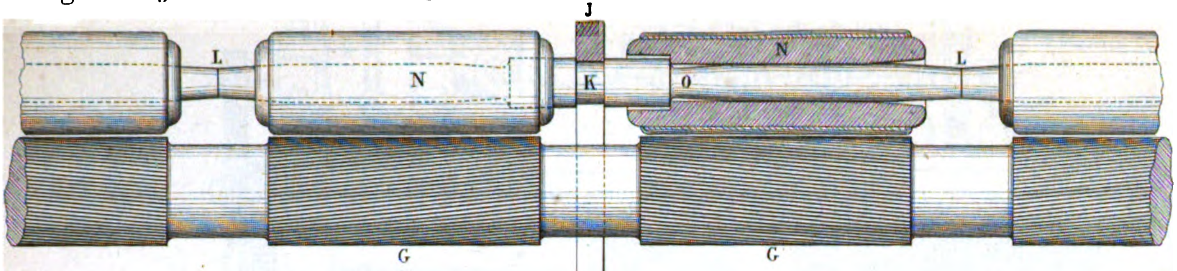


Fig. 8. *Transverse Section.*

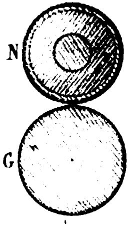


Fig. 9. *Eccentric Fluting Machine.*

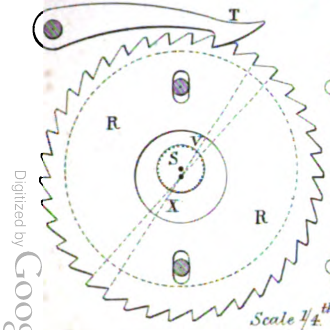
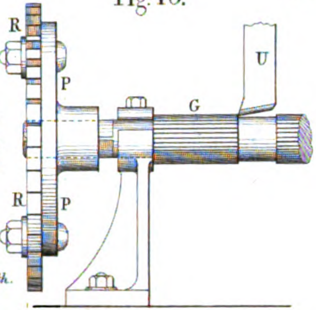


Fig. 10.



Scale 1/4th.

Milling Tool for milling the rollers.

Fig. 11.

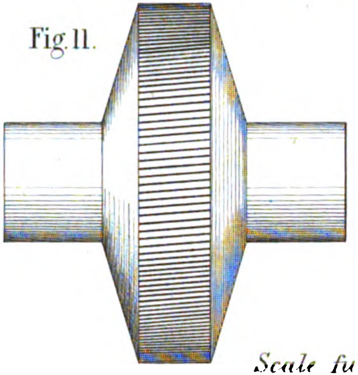
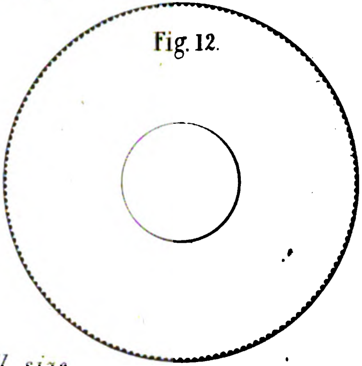


Fig. 12.

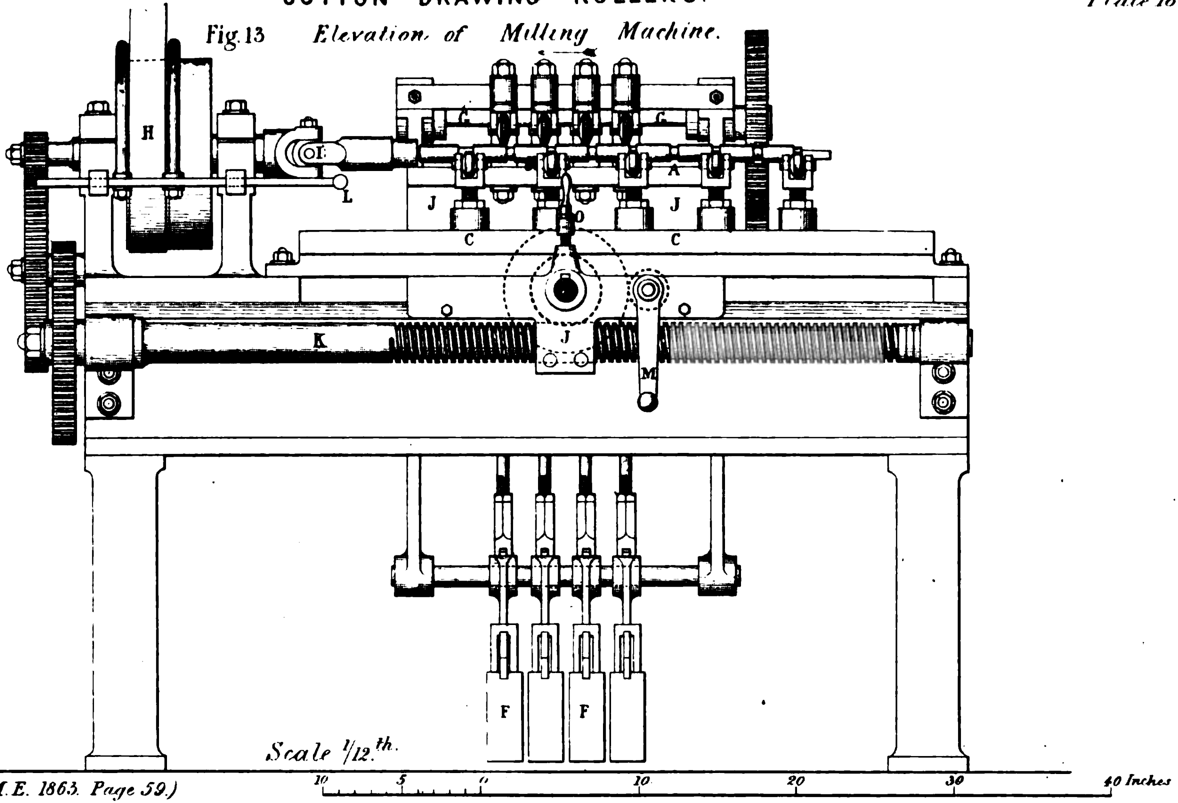


Scale full size.

(Proceedings Inst. M.E. 1863. Page 59.)

COTTON DRAWING ROLLERS.

Fig. 13 *Elevation of Milling Machine.*



COTTON DRAWING ROLLERS. *Plate 17.*

Fig. 14. *Transverse Section of Milling Machine.*

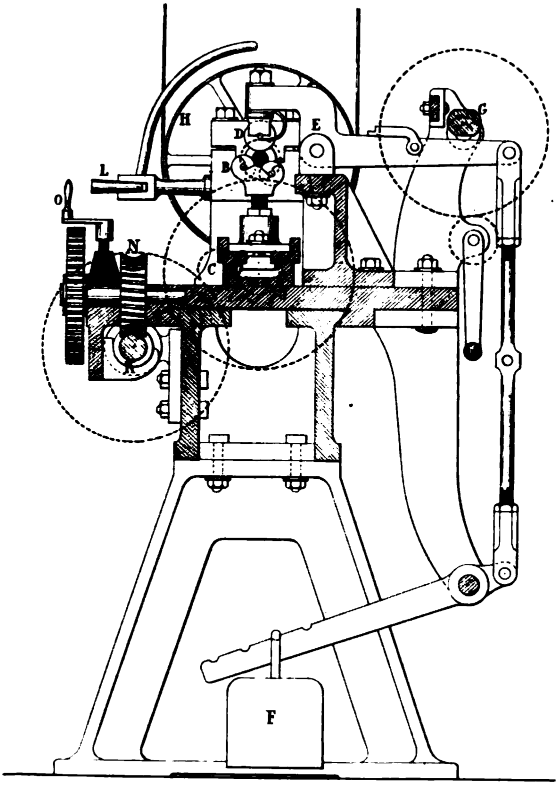
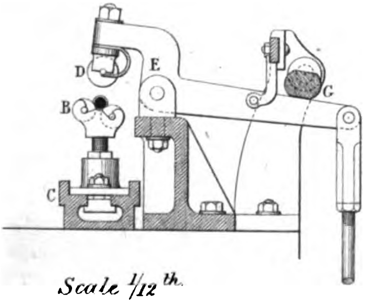


Fig. 15. *Transverse Section showing Mills lifted off Roller.*



Scale 1/12 th.

(Proceedings Inst. M. E. 1863. Page 59.)

COTTON DRAWING ROLLERS.

Fig. 16. *Elevation of Milling Tools in action.*

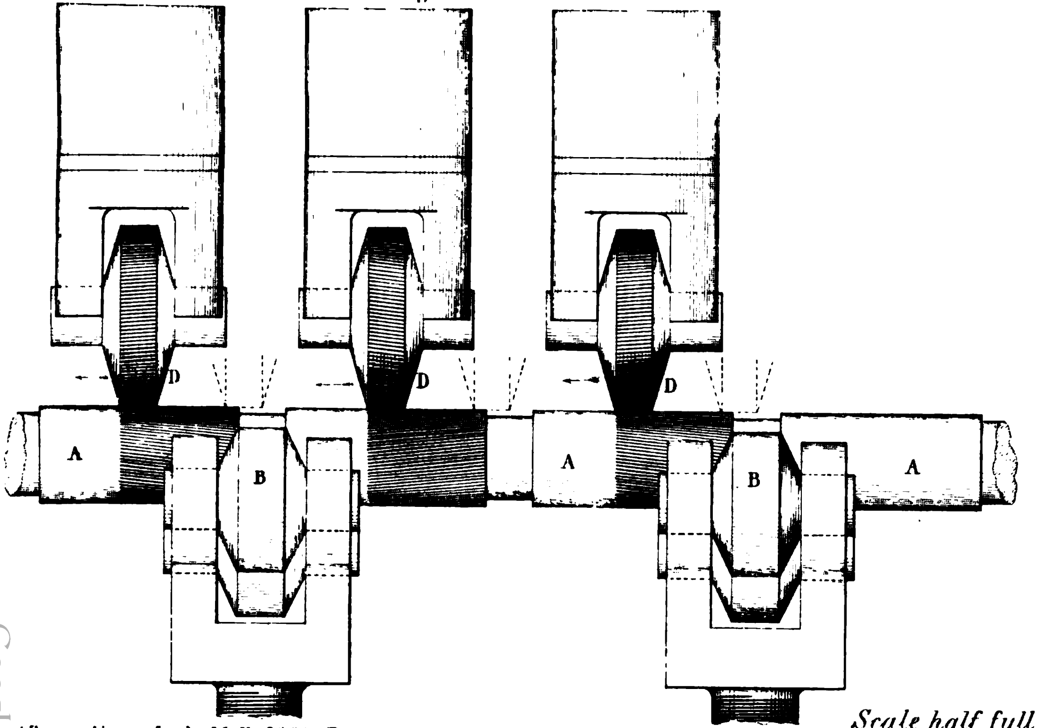
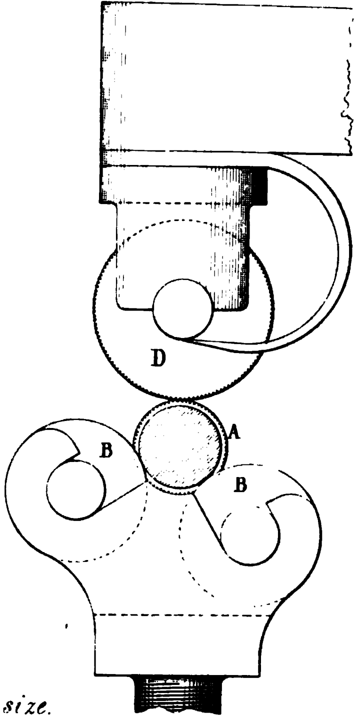


Fig. 17. *Transverse Section.*



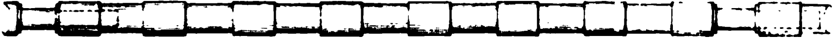
Scale half full size.

(Proceedings Inst. M.E. 1863. Page 59.)

COTTON DRAWING ROLLERS.

Plate 19.

Fig. 18. *Longitudinal Elevation of Drawing Roller, showing Coupling of successive lengths.* *Scale 1/6th.*



Full size. Sections of Couplings of Drawing Rollers.

Fig. 19. *Longitudinal Section of Bored Socket.*

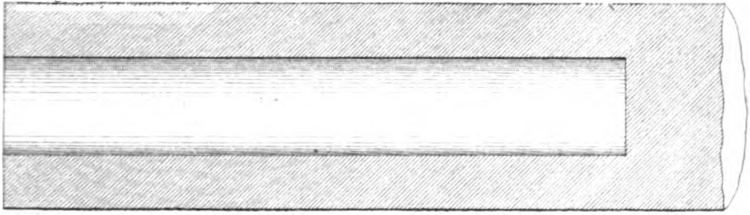
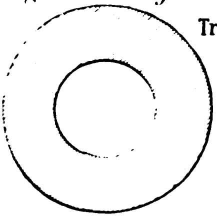
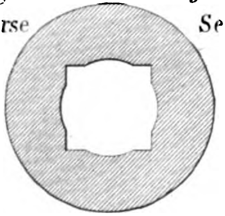


Fig. 20. *Boring.* Fig. 21. *First Punching.* Fig. 22. *Second Punching.*

Transverse Sections.





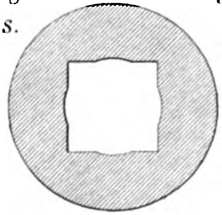


Fig. 23. *Longitudinal Section of finished Socket at XX (Fig. 24).*

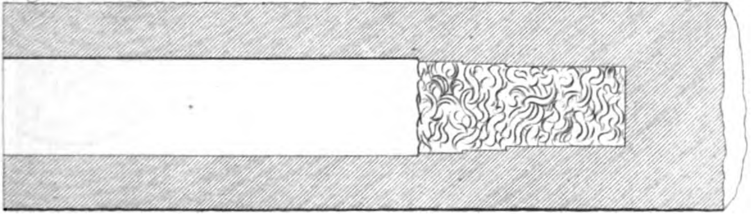


Fig. 24. *Finished Socket.* *Third Punching.*

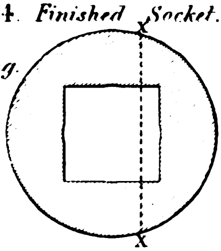
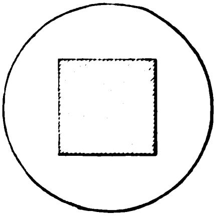
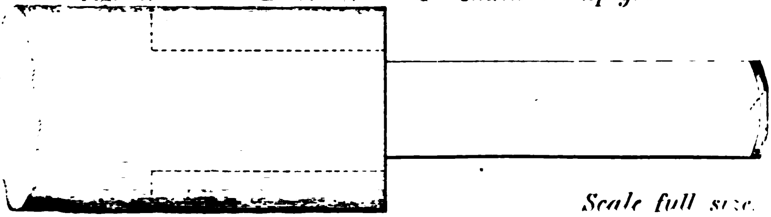


Fig. 25. *Finished Spigot.*



Transverse Sections.

Fig. 26. *Side Elevation of finished Spigot.*



Scale full size.

(Proceedings Inst. M.E. 1863. Page 59)

COTTON DRAWING ROLLERS.

Plate 20.

Fig. 27. *Drawing Rollers for Short fibred cotton. Full size.*

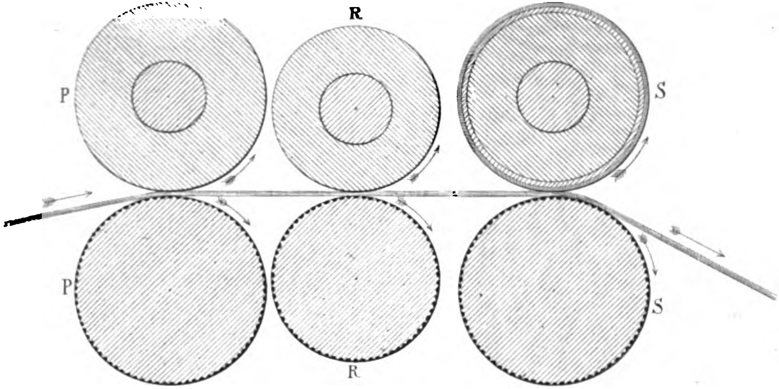


Fig. 28. *Drawing Rollers for Long fibred cotton. Full size.*

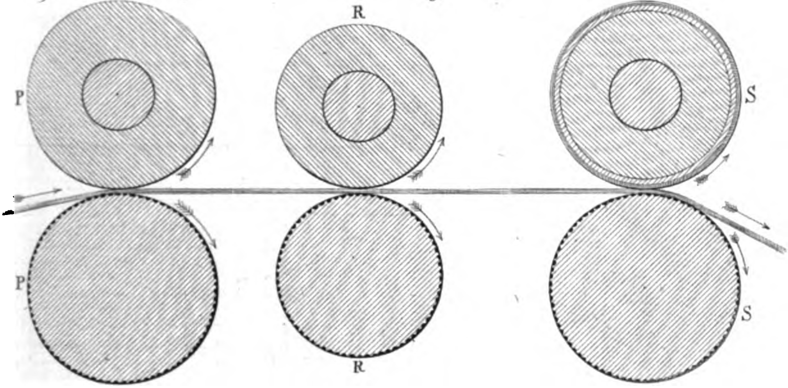


Fig. 29. *Diagram of Drawing Action.*

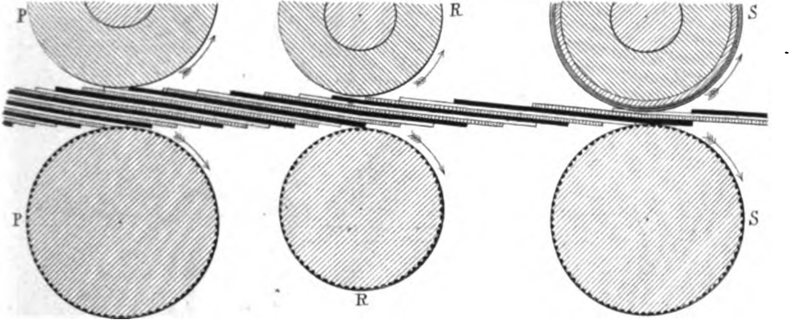
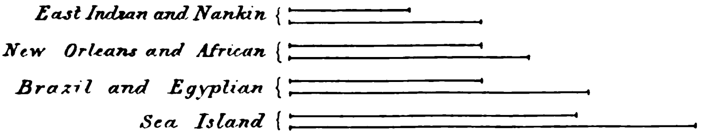


Fig. 30. *Lengths of Cotton Fibres. Full size.*



(Proceedings Inst. M. E. 1863. Page 59.)

London and North Western Outside Cylinder Express Engine.

Fig. 1.

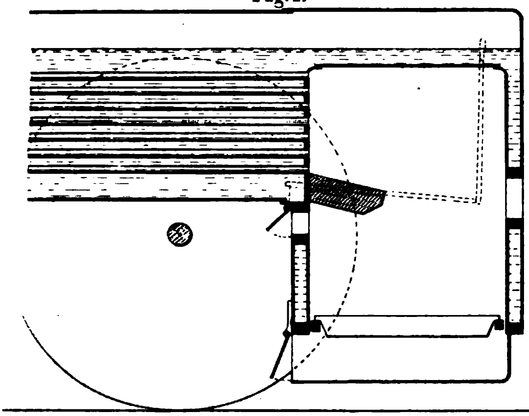


Fig. 2.

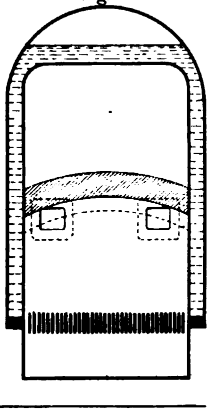


Fig. 3. *London Chatham and Dover Goods Engine.*

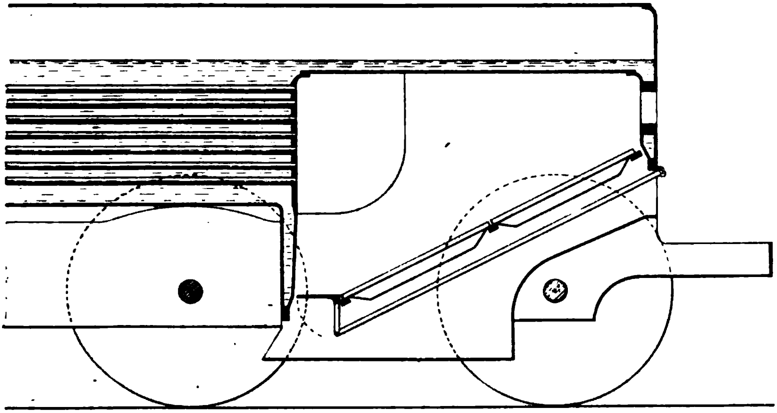
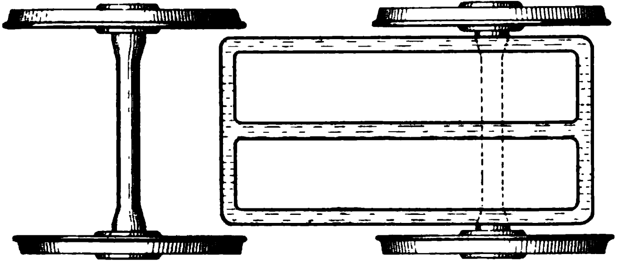


Fig. 4. *Plan.*

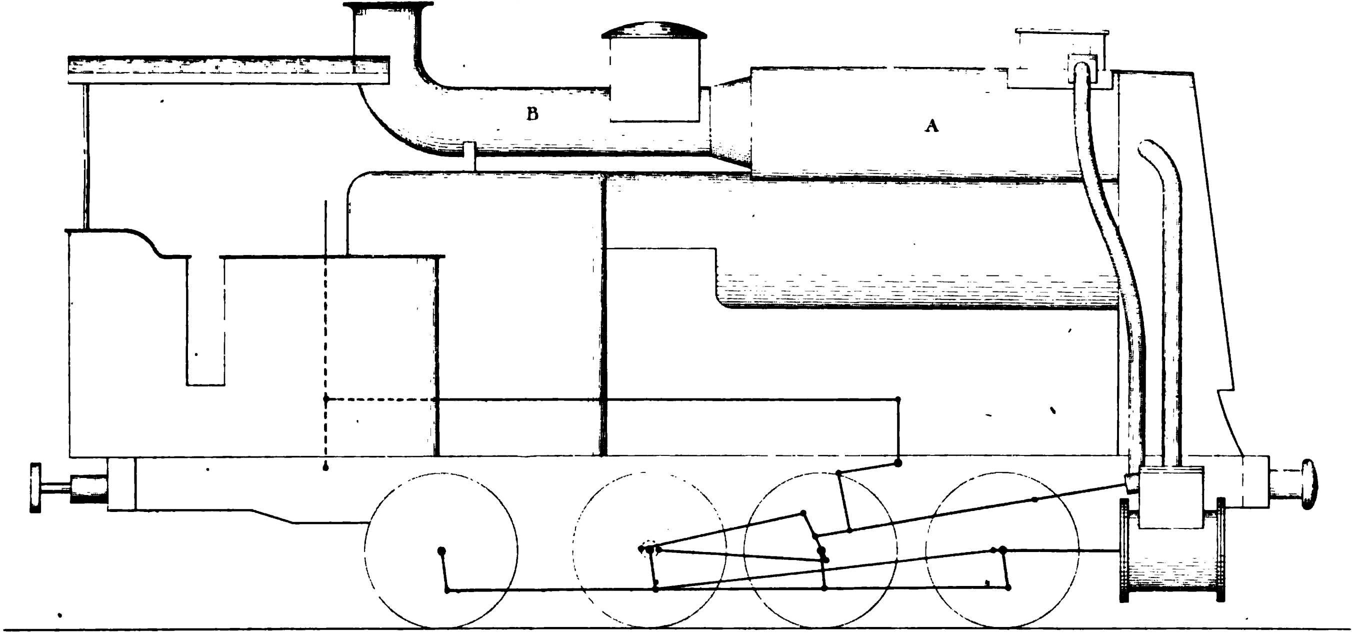


(Proceedings Inst. M.E. 1863. Page 78.)

LOCOMOTIVES IN EXHIBITION 1862.

Northern Railway of France "Dromadaire" Heavy Tank Engine.

Fig. 5. *Side Elevation.*



(Proceedings Inst. M.E. 1863. Page 78.)

LOCOMOTIVES IN EXHIBITION 1862.

Northern Railway of France, "Dromadaire" Heavy Tank Engine.

Fig. 6. *Transverse Section through Firebox.*

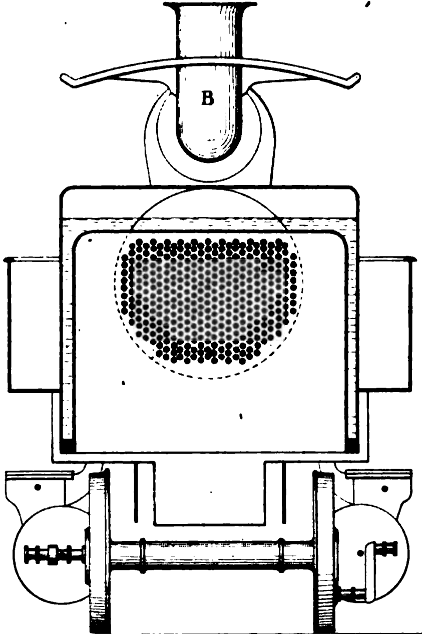
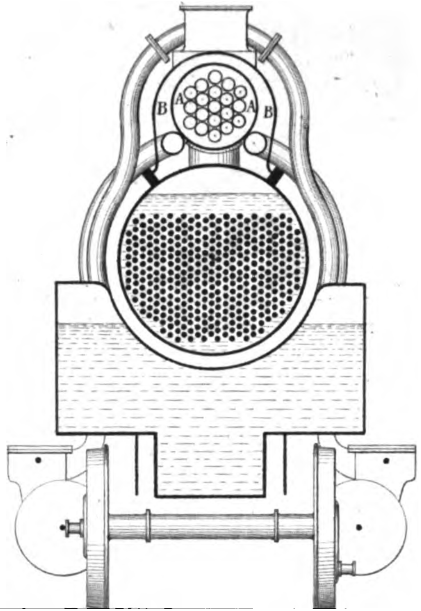


Fig. 7. *Transverse Section through Boiler.*



LOCOMOTIVES IN EXHIBITION 1862.

Fig. 8. *Elevation of Meyer's Engine.*

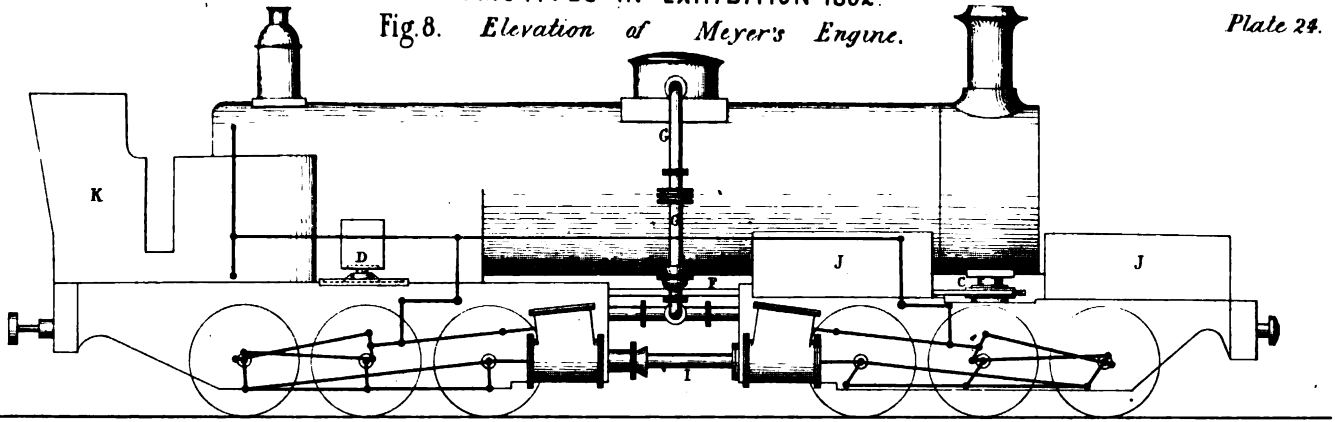
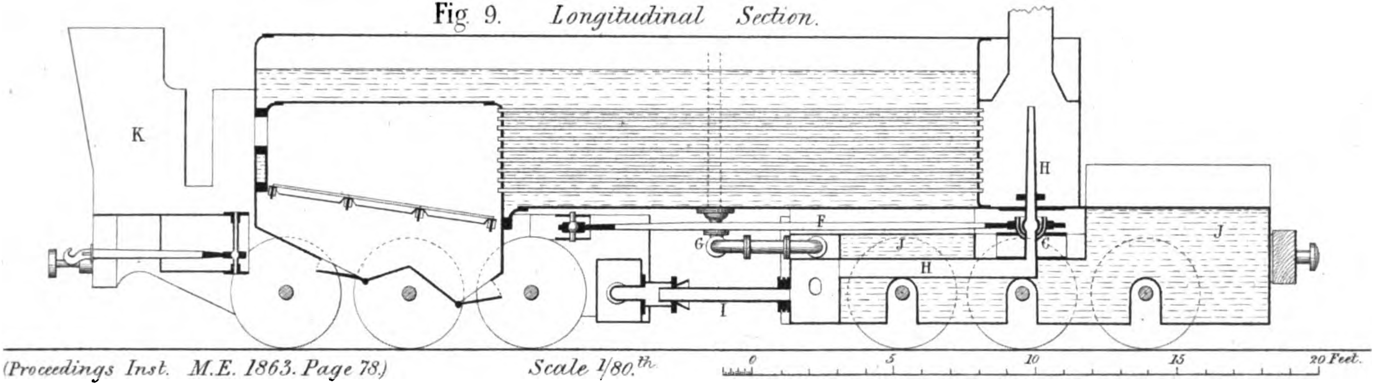


Fig. 9. *Longitudinal Section.*



(Proceedings Inst. M.E. 1863. Page 78.)

Scale 1/80th

LOCOMOTIVES IN EXHIBITION 1862.

Fig. 10. *Plan of Meyer's Engine.*

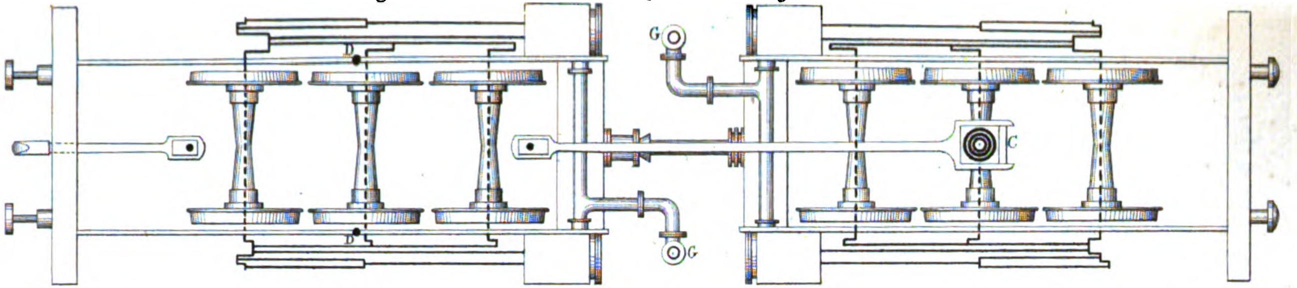


Fig. 12. *Transverse Section.*

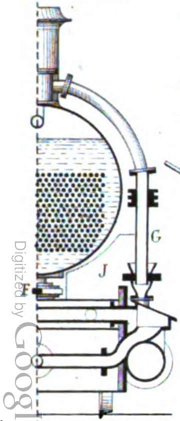
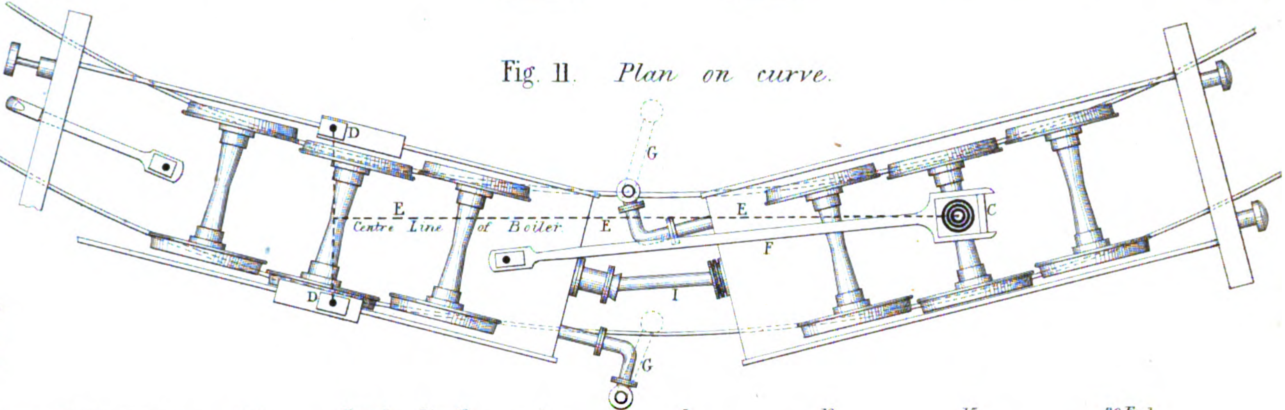


Fig. 11. *Plan on curve.*



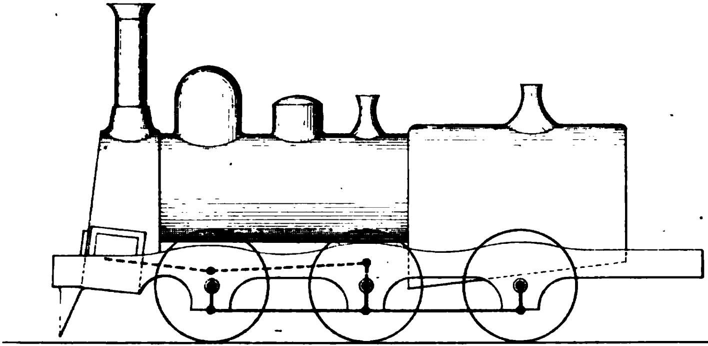
(Proceedings Inst. M.E. 1863. Page 78.)

Scale 1/80th.

0 5 10 15 20 Feet.

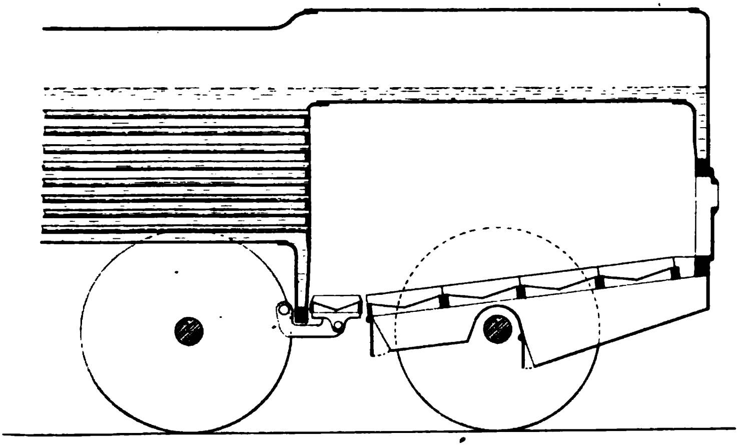
Belgian State Railway Goods Engine.

Fig. 13. *Side Elevation.*



Scale 1/100th.

Fig. 14. *Longitudinal Section of Firebox.*



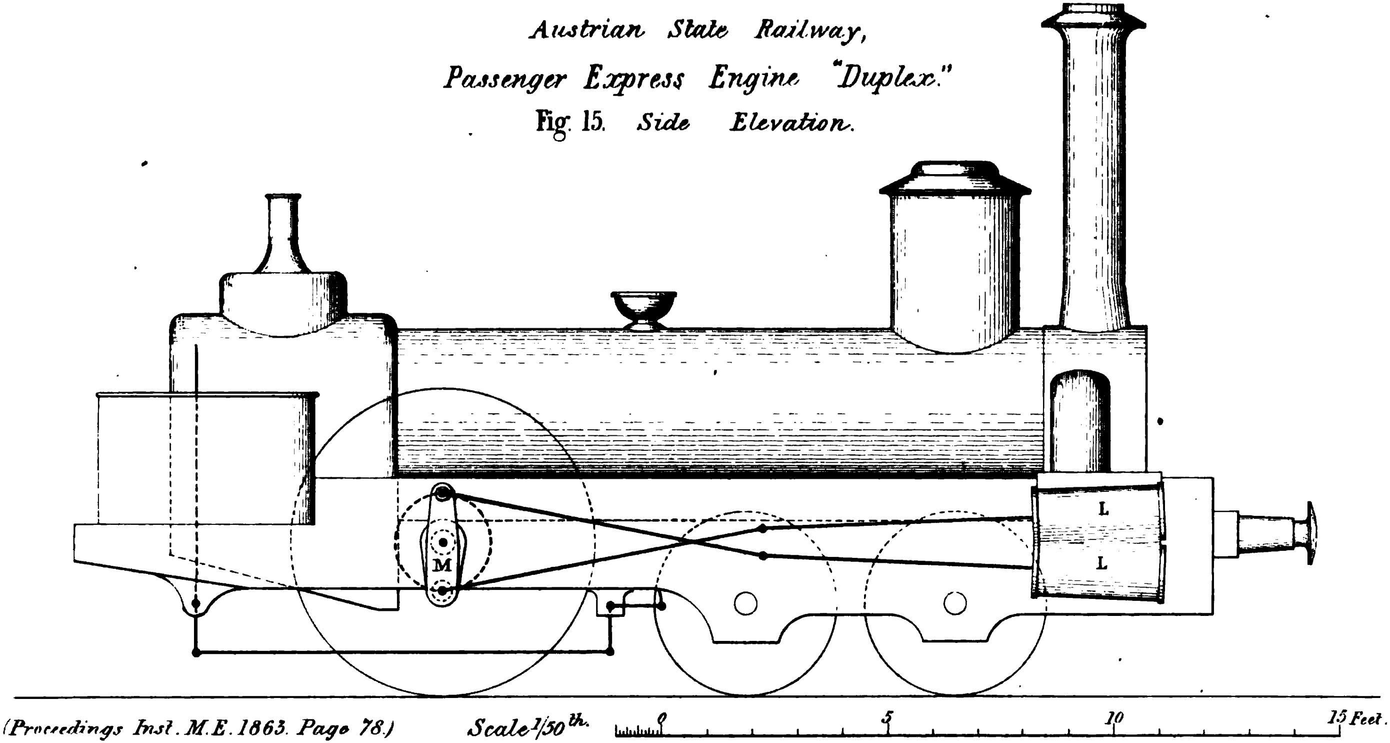
Scale 1/50th.

LOCOMOTIVES IN EXHIBITION 1862.

Austrian State Railway,

Passenger Express Engine "Duplex."

Fig. 15. *Side Elevation.*



(Proceedings Inst. M.E. 1863. Page 78.)

Scale 1/50th.

LOCOMOTIVES IN EXHIBITION 1862.

Austrian State Railway, Passenger Express Engine "Duplex."

Fig. 16. *Half Plan. Scale 1/50th*

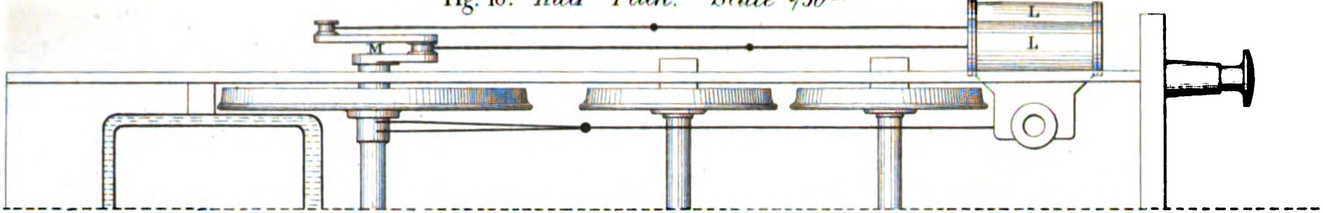


Fig. 17. *Transverse Section of Cylinders at XX.*

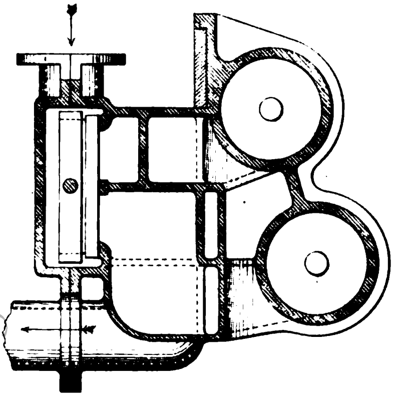


Fig. 18. *Longitudinal Section of Upper Cylinder and Valve chest.*

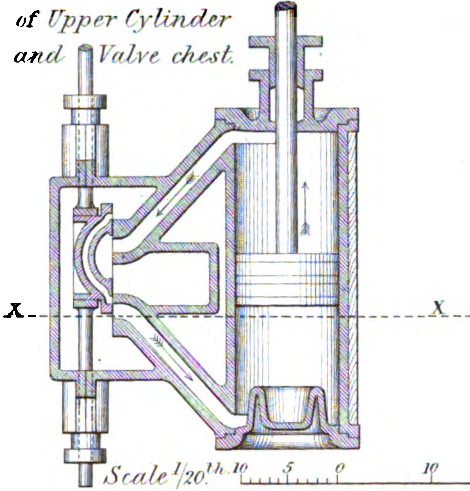
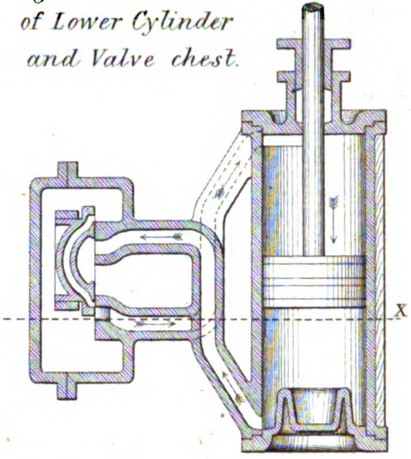


Fig. 19. *Longitudinal Section of Lower Cylinder and Valve chest.*



(*Proceedings Inst. M.E. 1863. Page 78.*)

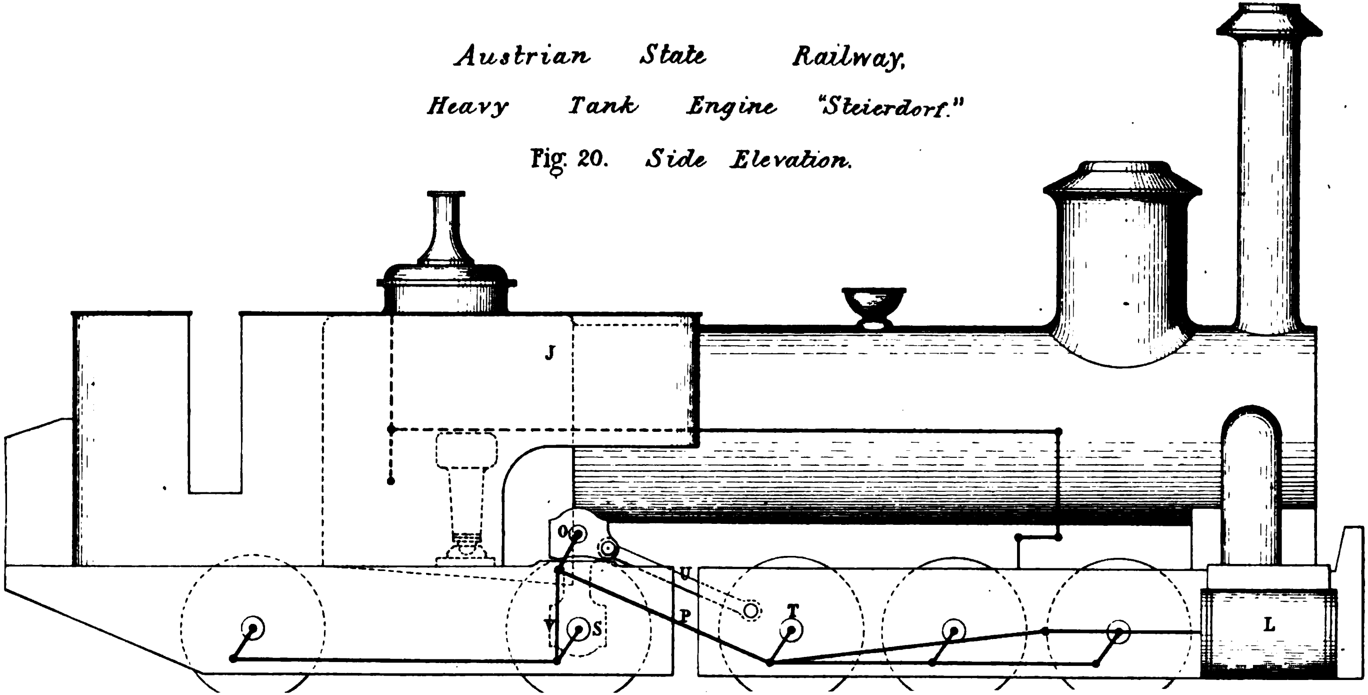
Plate 29.

LOCOMOTIVES IN EXHIBITION 1862.

Austrian State Railway,

Heavy Tank Engine "Steierdorf."

Fig. 20. *Side Elevation.*



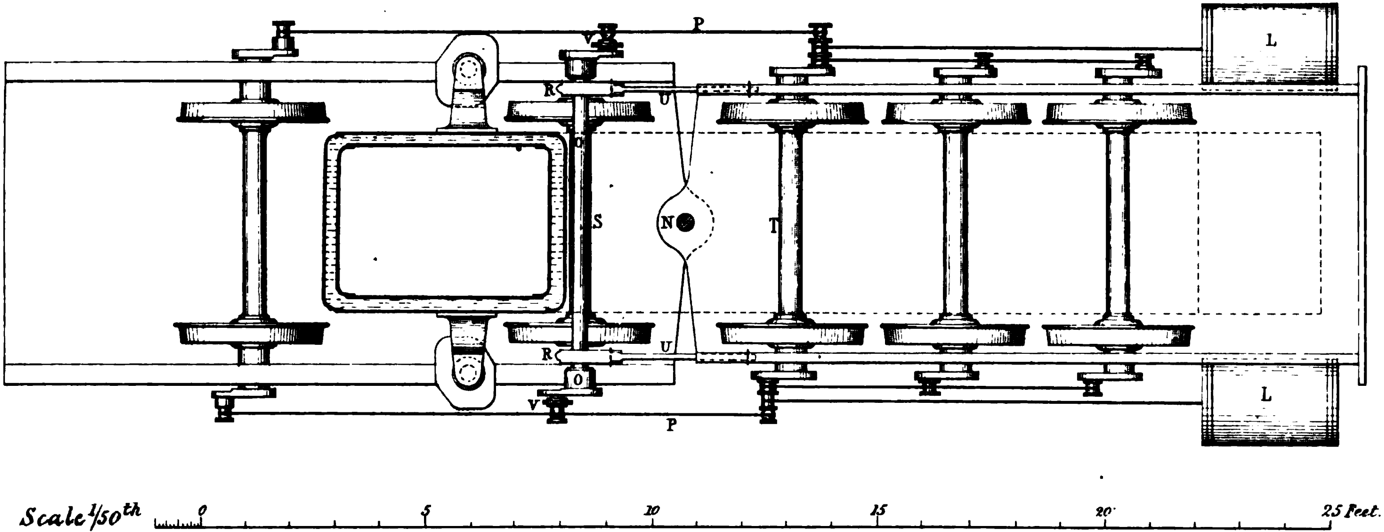
LOCOMOTIVES IN EXHIBITION 1862.

Plate 30.

Austrian State Railway.

Heavy Tank Engine "Steierdorf"

Fig. 21. *Plan.*

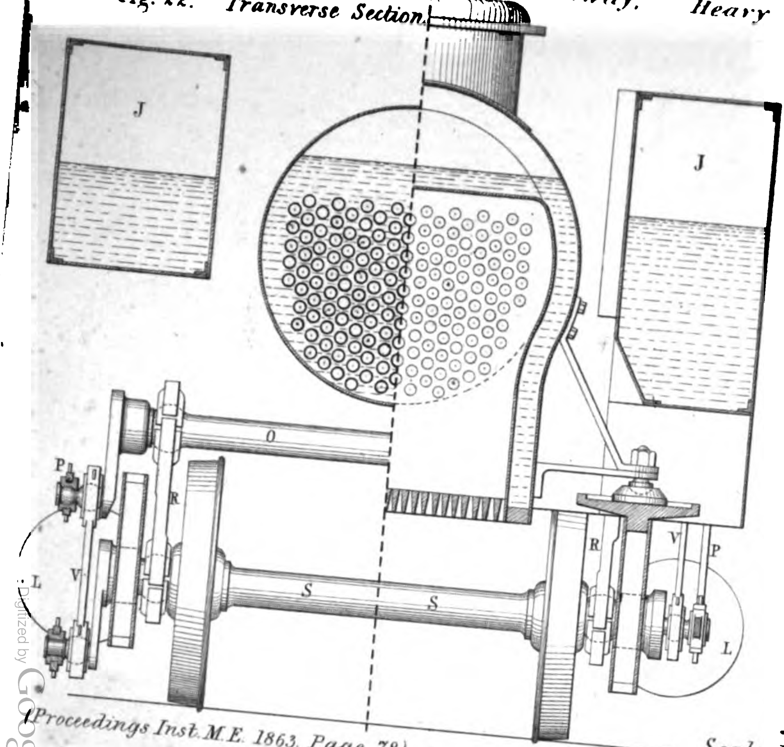


(Proceedings Inst. M.E. 1863. Page 78.)

LOCOMOTIVES IN EXHIBITION 1862.

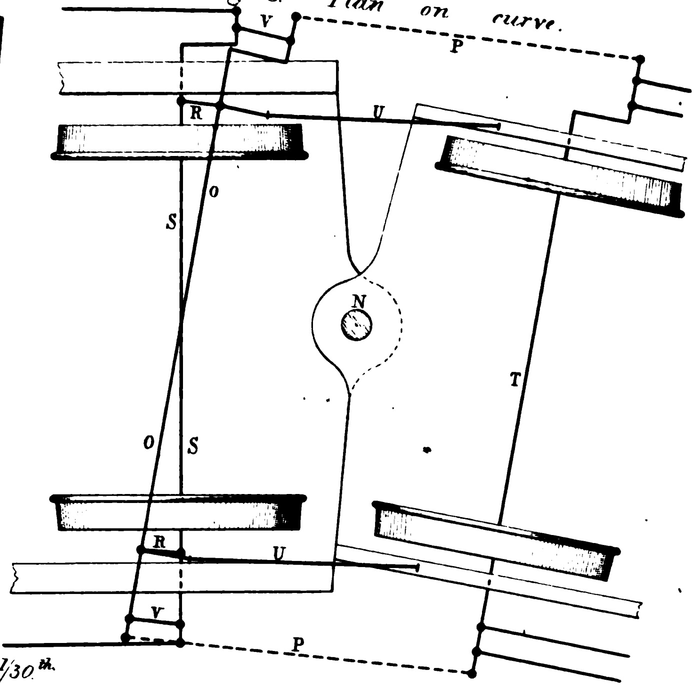
Austrian State Railway. Heavy Tank Engine "Steierdorf"

Fig. 22. Transverse Section.



(Proceedings Inst. M.E. 1863. Page 78)

Fig. 23. Plan on curve.



Scale 1/30th.

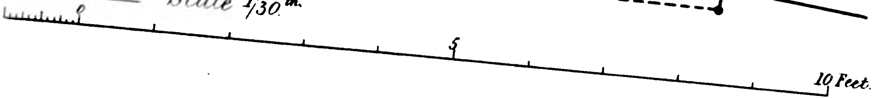


Plate 32.

CONSTRUCTION OF IRON SHIPS.

Fig. 1. 1200 ton Iron Ship supported at ends.

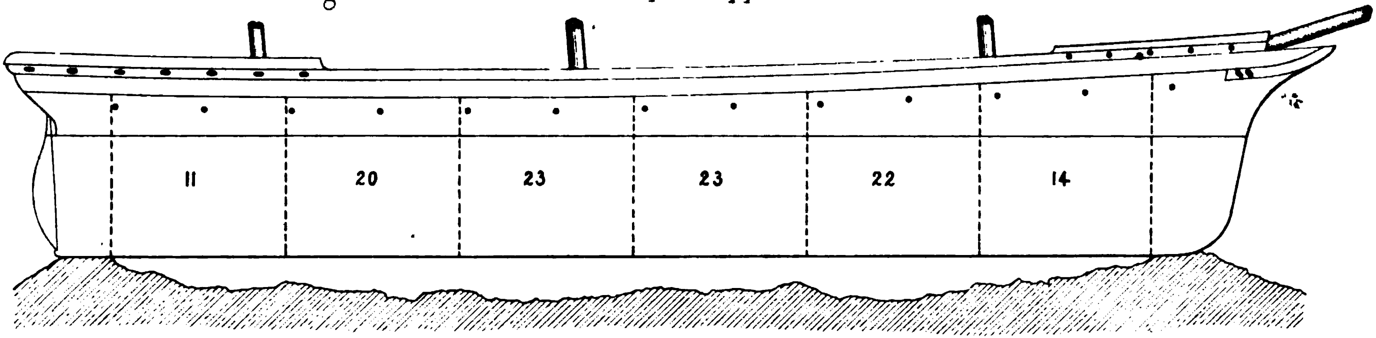
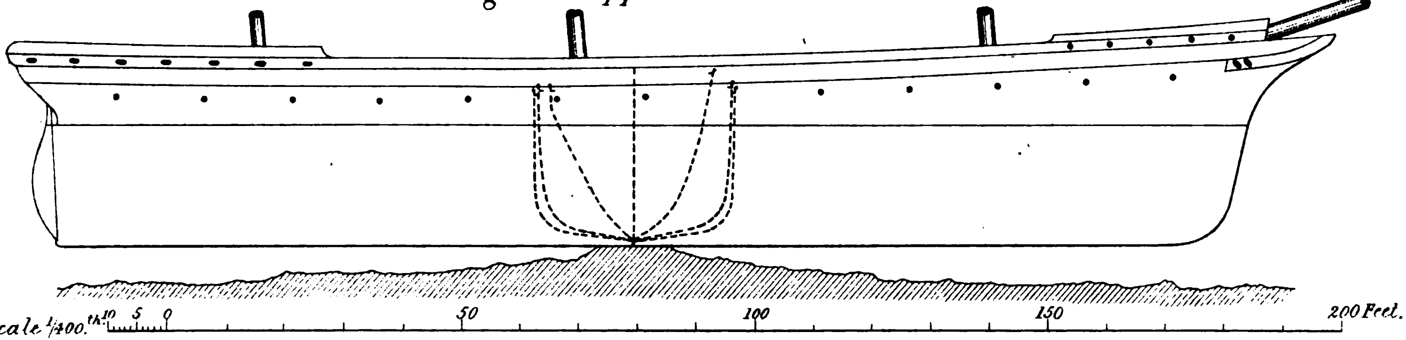


Fig. 2. Supported at centre.



(Proceedings Inst. M.E. 1863. Page 115.)

CONSTRUCTION OF IRON SHIPS.

Fig. 3. *Transverse Section of 1200 ton Iron Ship.*

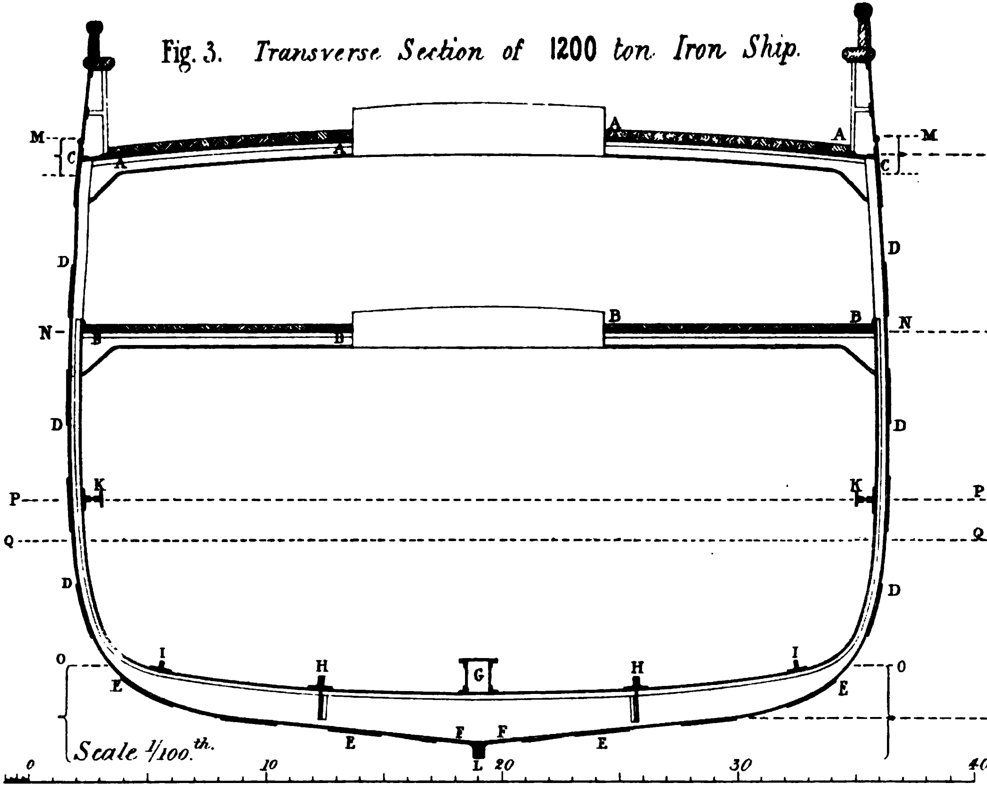
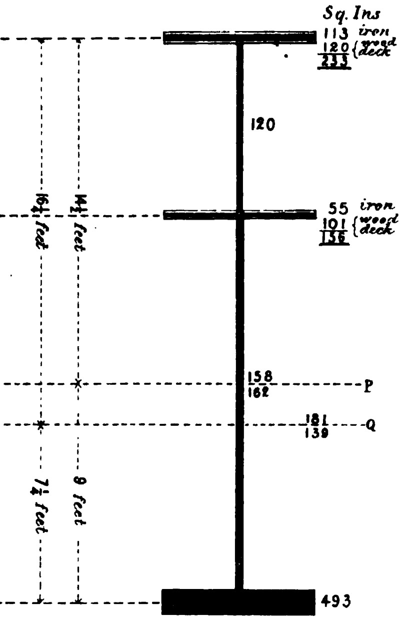


Fig. 4. *Area of Section.*
Scale 1/5000th. of actual area.



CONSTRUCTION OF IRON SHIPS.

Plate 34.

Fig. 5. *Transverse Section of 1200 ton Wood Ship.*

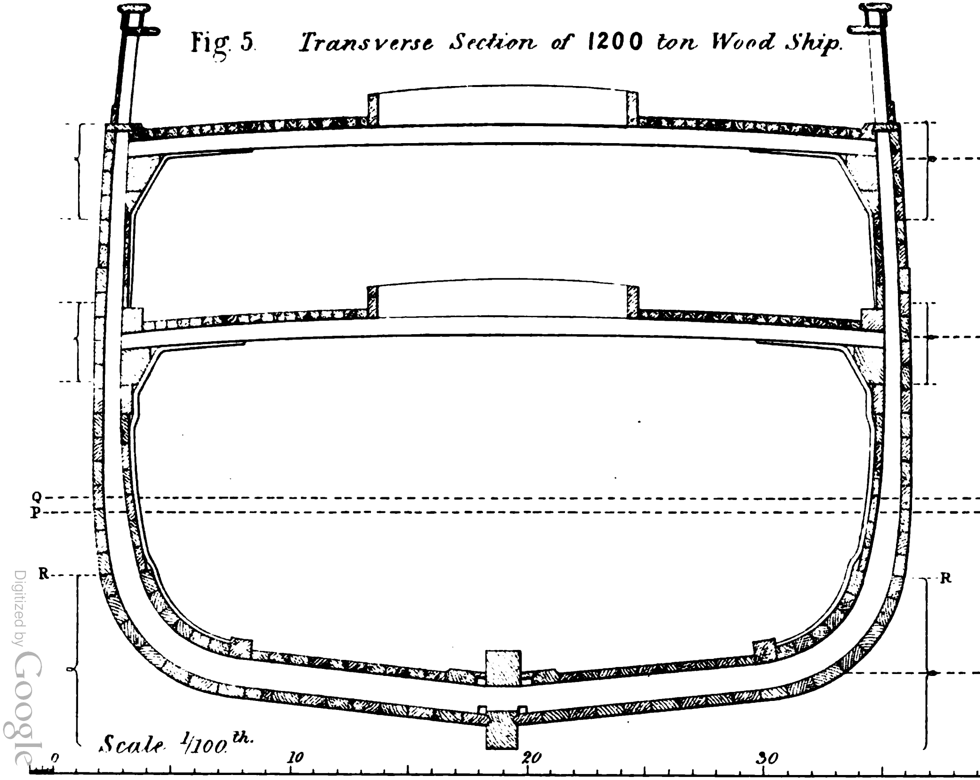
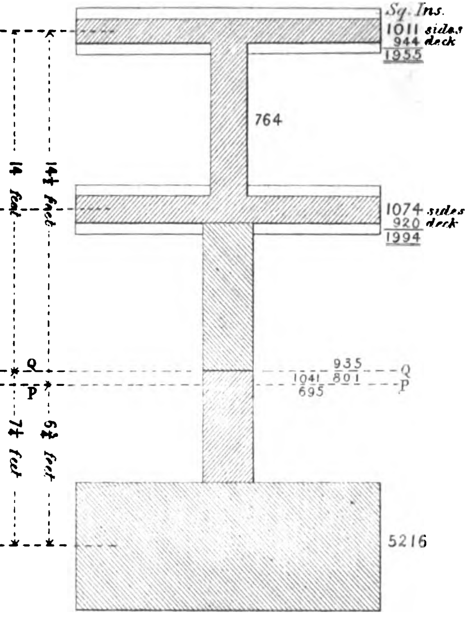


Fig. 6. *Area of Section.*
Scale 1/5000th of actual area.



(Proceedings Inst. M.E. 1863. Page 115)

CONSTRUCTION OF IRON SHIPS. *Plate 35.*

Sections of Keels.

Fig. 7.
Ordinary Keel.

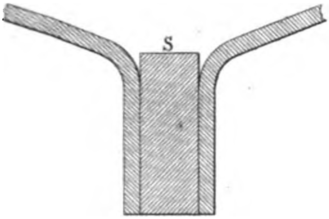


Fig. 8. *Flat Plate Keel*
for flat bottomed vessels.

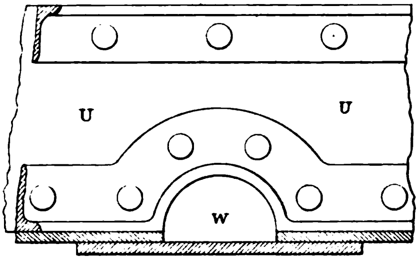


Fig. 9. *Deep Plate Keel.*

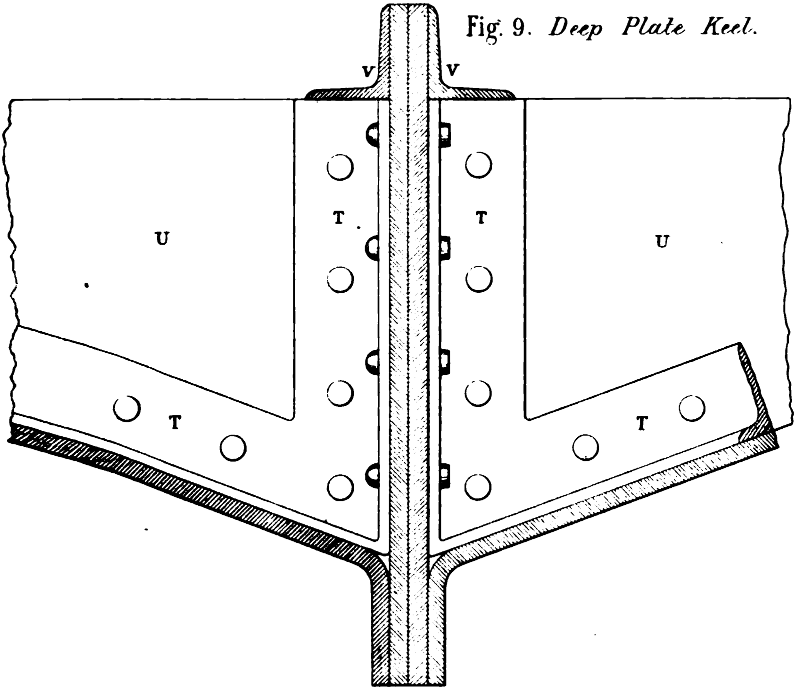
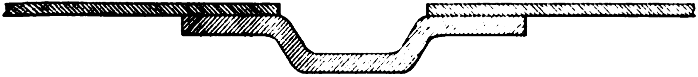


Fig. 10. *Dished Keel for flat bottomed vessels.*



Scale 1/10th

(Proceedings Inst. M. E. 1863. Page 115.)

CONSTRUCTION OF IRON SHIPS. *Plate 36.*

Sections of Keelsons.

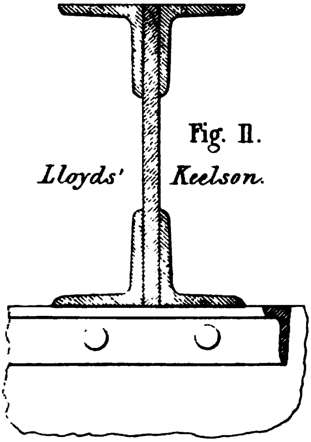


Fig. 11.
Lloyds' Keelson.

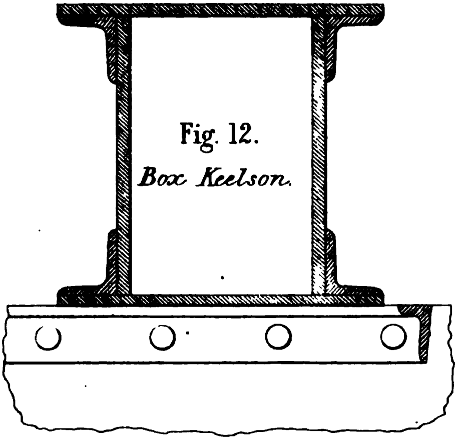


Fig. 12.
Box Keelson.

Fig. 13.
Intercostal Keelson.

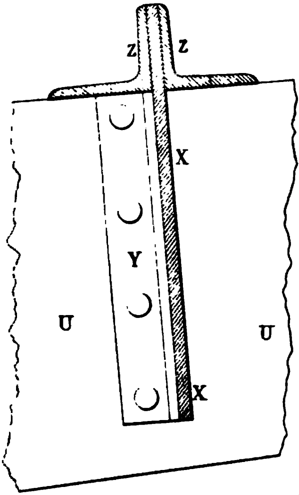
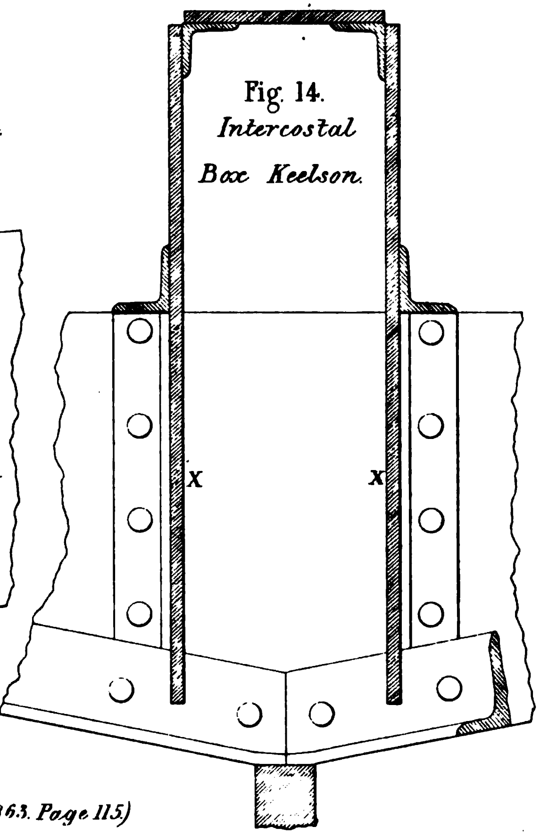


Fig. 14.
Intercostal Box Keelson.



(Proceedings Inst. M.E. 1863. Page 115.)

Scale $1/10^{th}$ 0 10 20 30 *Inches.*

CONSTRUCTION OF IRON SHIPS.

Plate 37.

Sections of Stringers.

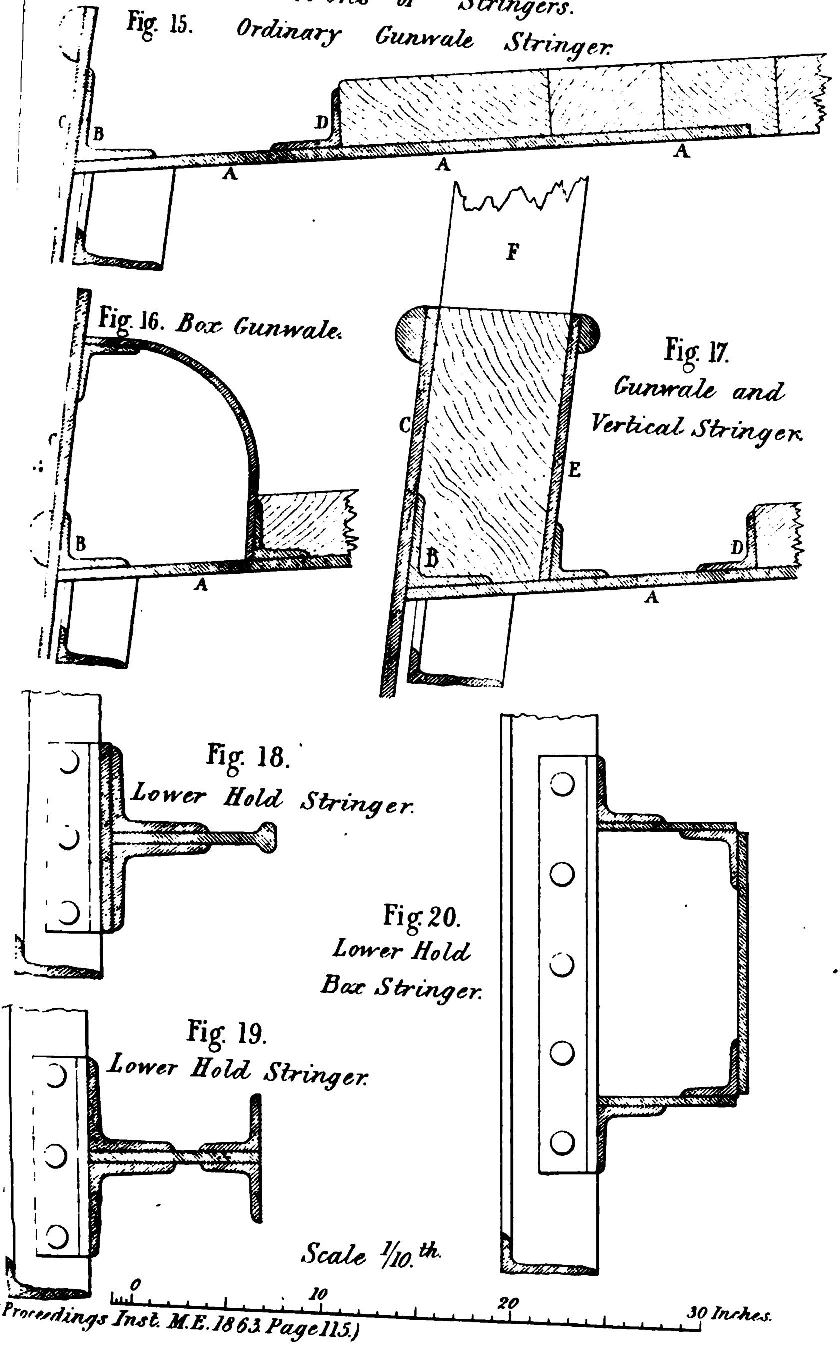


Fig. 15. *Ordinary Gunwale Stringer.*

Fig. 16. *Box Gunwale.*

Fig. 17. *Gunwale and Vertical Stringer.*

Fig. 18. *Lower Hold Stringer.*

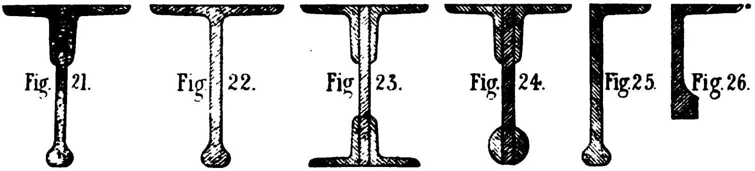
Fig. 19. *Lower Hold Stringer.*

Fig. 20. *Lower Hold Box Stringer.*

Scale 1/10th.

Proceedings Inst. M.E. 1863 Page 115.)

Sections of Deck Beams.



Sections of Frame Iron.

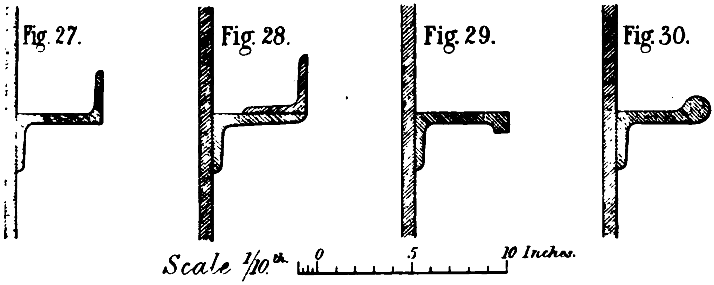


Fig. 34.

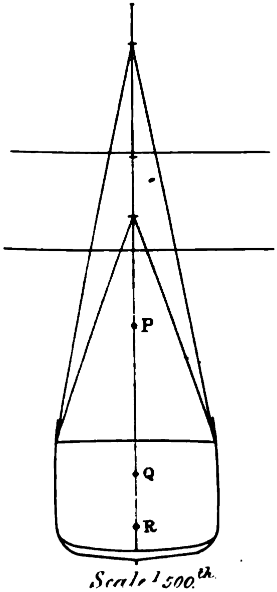
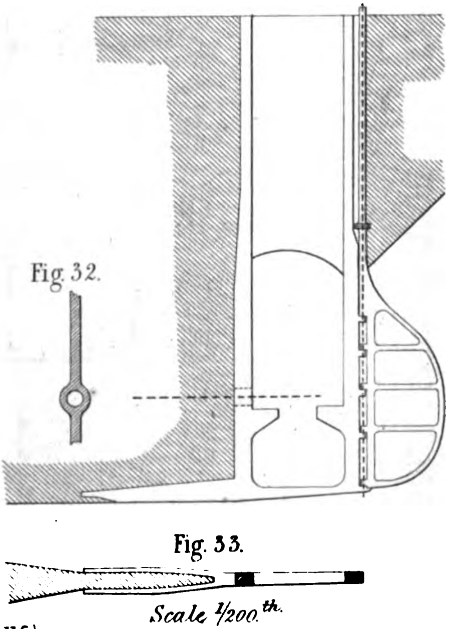
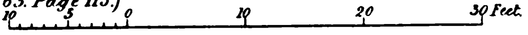


Fig. 31. *Stern Post and Screw Port Frame of "Great Britain."*



(Proceedings Inst. M.E. 1863. Page 115.)



CONSTRUCTION OF IRON SHIPS.

Plate 39.

Iron Screw Collier
with Water Ballast.

Fig. 35. Transverse Section. Scale 1/100th

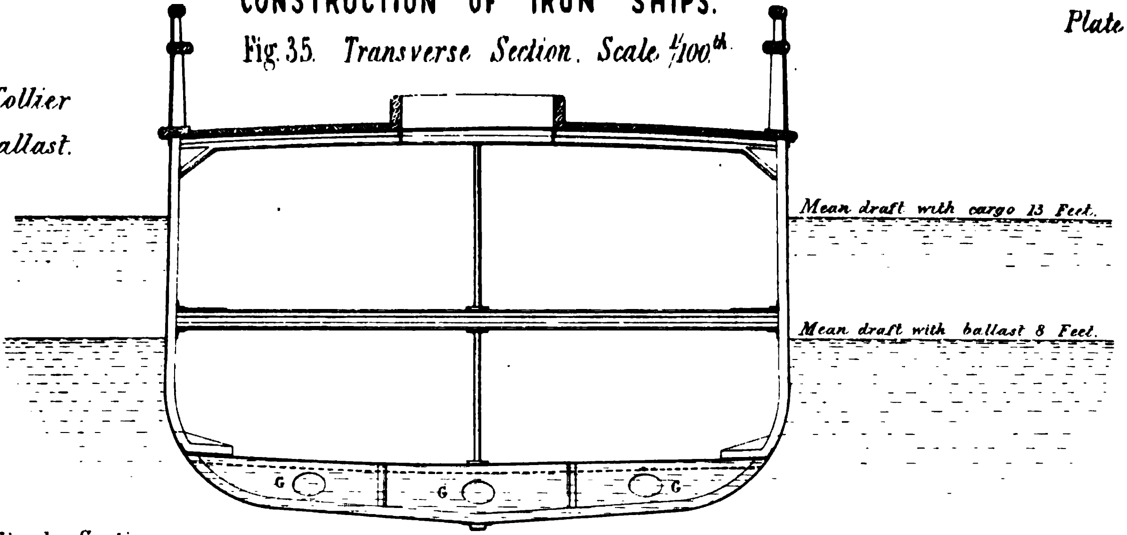
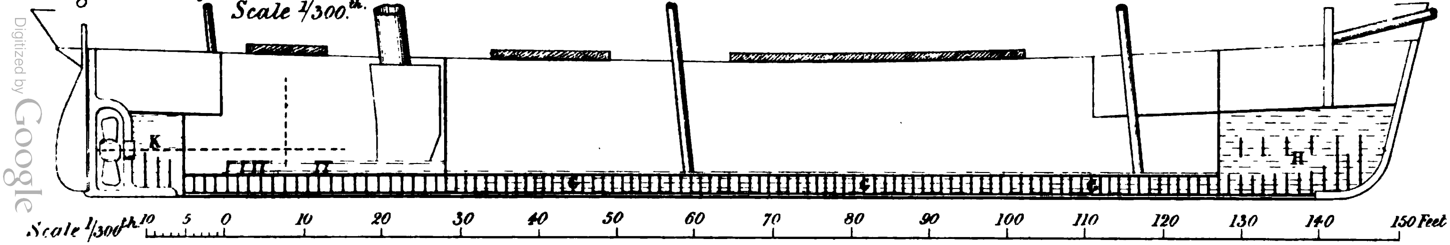

Mean draft with cargo 13 Feet.
Mean draft with ballast 8 Feet.
G
G
G

Fig. 36. Longitudinal Section. Scale 1/300th.



(Proceedings Inst. M.E. 1863. Page 115.)

CONSTRUCTION OF IRON SHIPS.

Plate 40

Flat Bottomed River Boat.

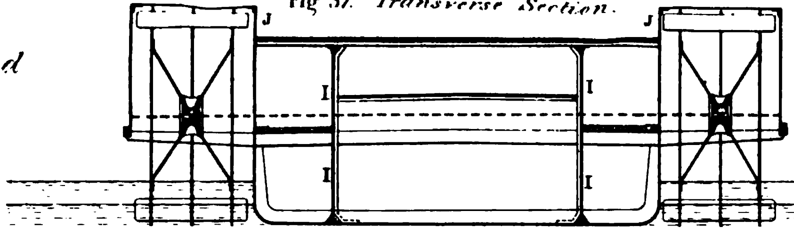
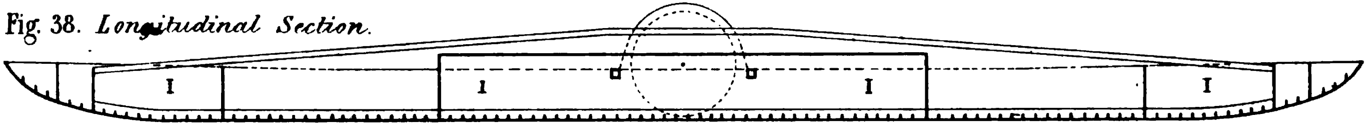


Fig 37. *Transverse Section.*

Scale 1/200th.

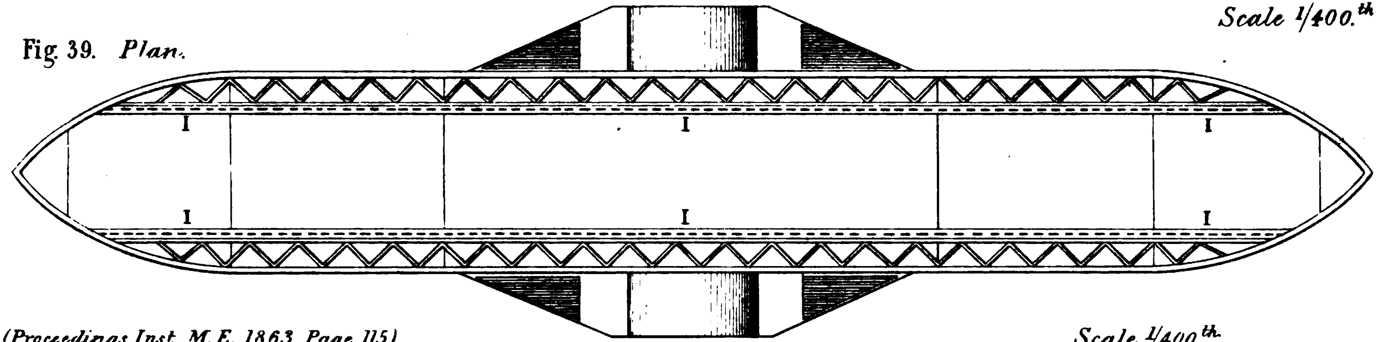
Mean draft when loaded 4 feet.
Mean draft when empty 2 feet.

Fig. 38. *Longitudinal Section.*



Scale 1/400th.

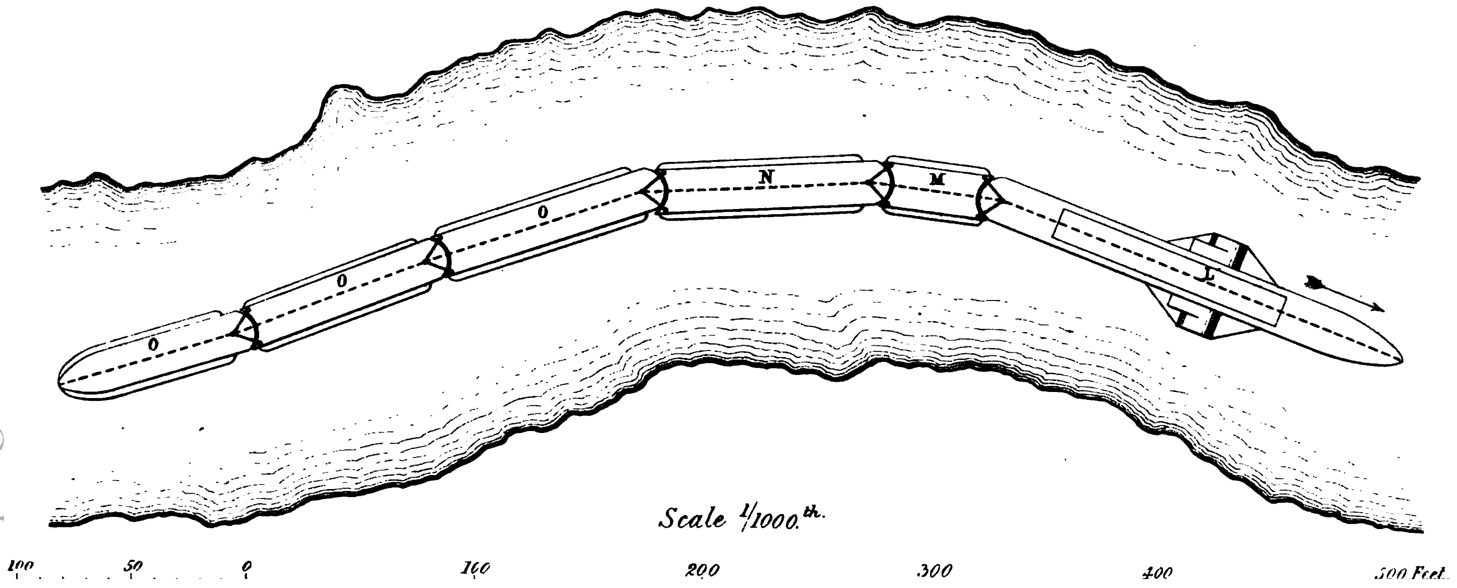
Fig. 39. *Plan.*



(Proceedings Inst. M.E. 1863. Page 115)

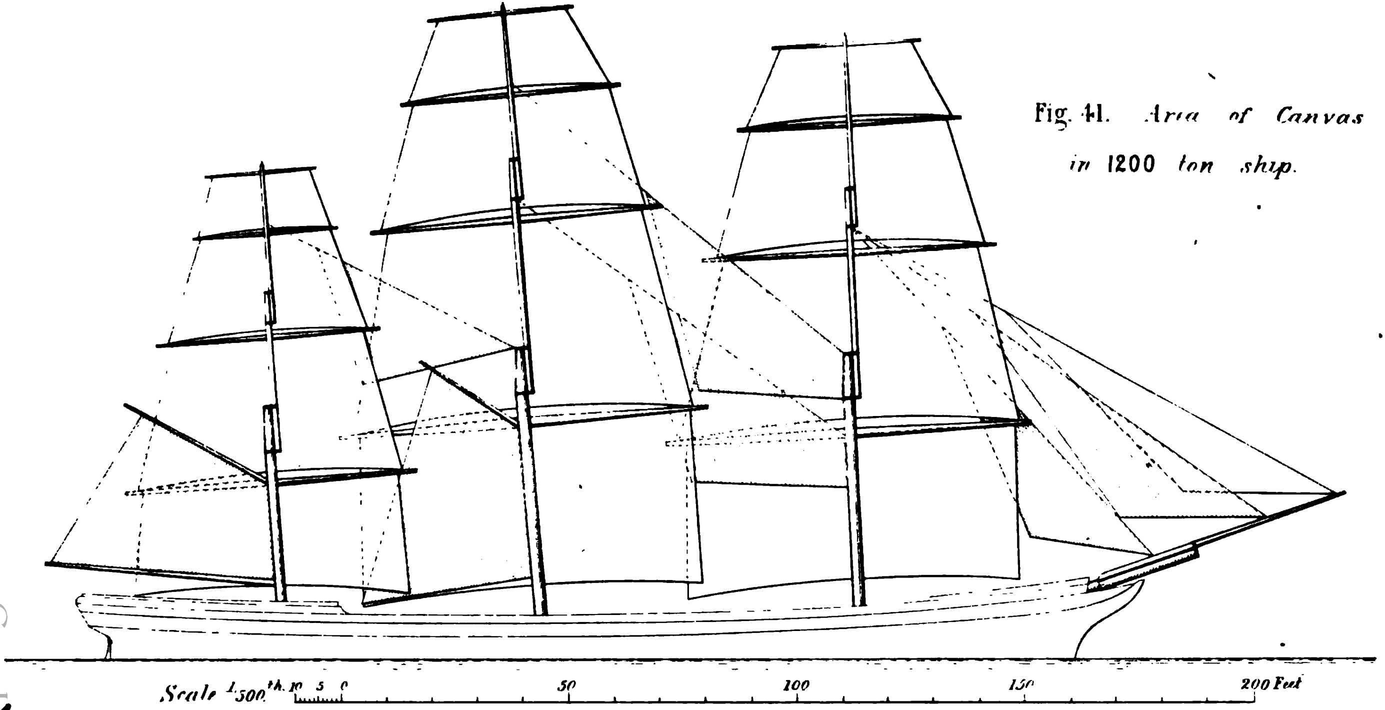
Scale 1/400th.

Fig. 40. *Bourne's Indian River Train.*



Scale 1/1000th.

Fig. 41. *Area of Canvas in 1200 ton ship.*



(Proceedings Inst M.E. 1863 Page 115.)

CONSTRUCTION OF IRON SHIPS.

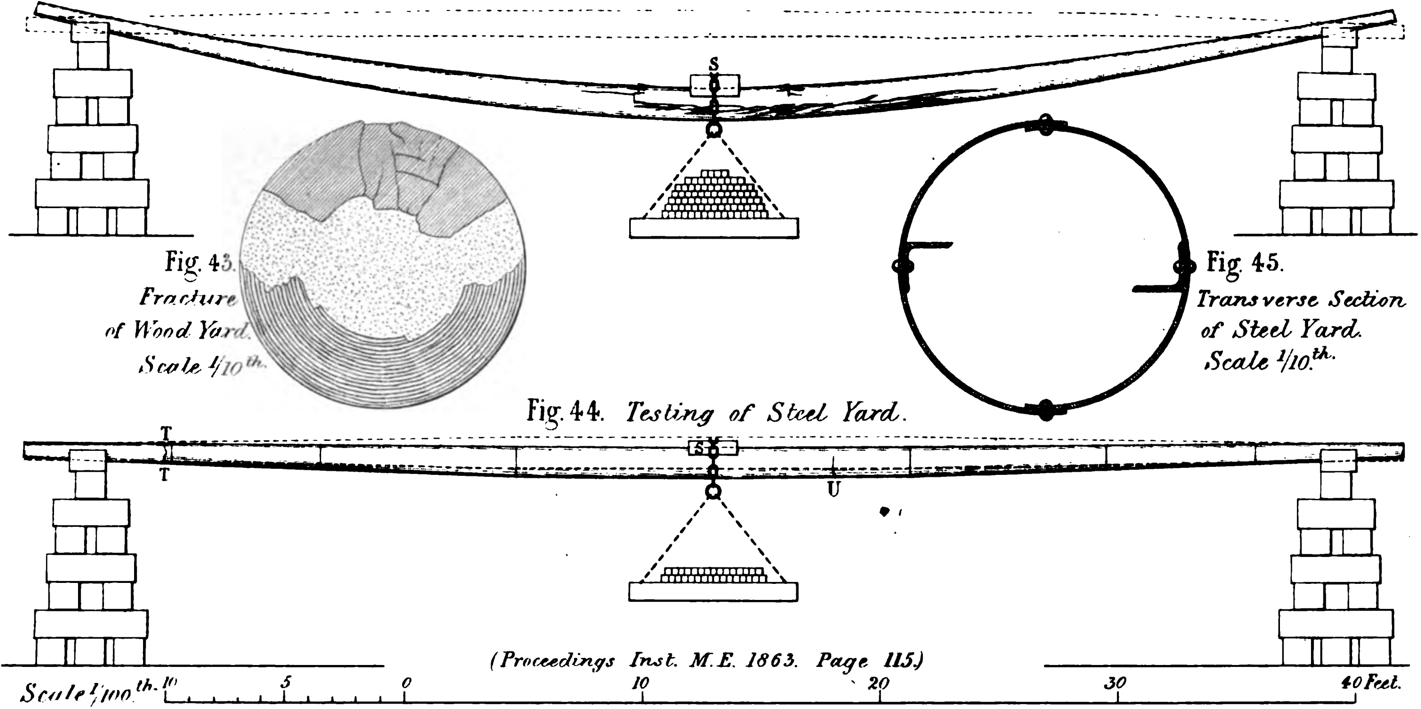


Fig. 42. Testing of Wood Yard.

Fig. 43. Fracture of Wood Yard. Scale 1/10th.

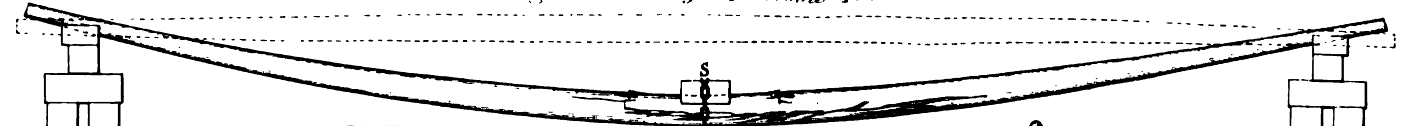
Fig. 44. Testing of Steel Yard.

Fig. 45. Transverse Section of Steel Yard. Scale 1/10th.

(Proceedings Inst. M.E. 1863. Page 115.)

CONSTRUCTION OF IRON SHIPS.

Fig. 42. Testing of Wood Yard.



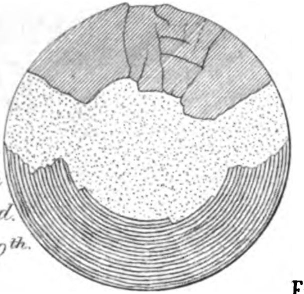


Fig. 43. Fracture of Wood Yard. Scale 1/10th.

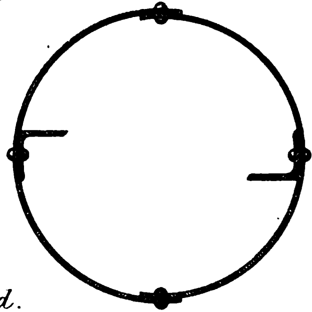
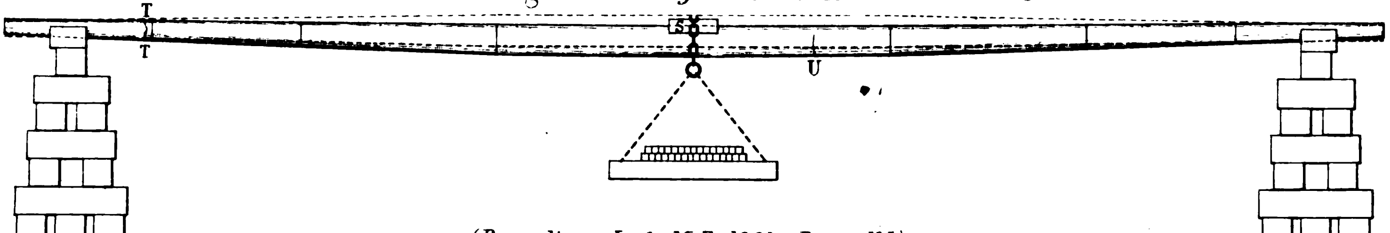


Fig. 45. Transverse Section of Steel Yard. Scale 1/10th.

Fig. 44. Testing of Steel Yard.



(Proceedings Inst. M.E. 1863. Page 115.)

LIVERPOOL WATER WORKS.

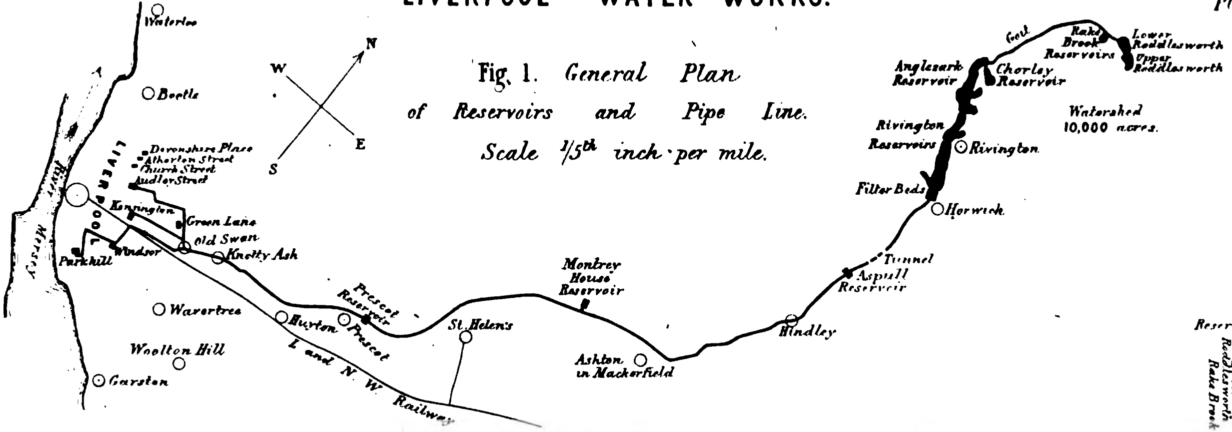


Fig. 1. General Plan of Reservoirs and Pipe Line.

Scale 1/5th inch per mile.

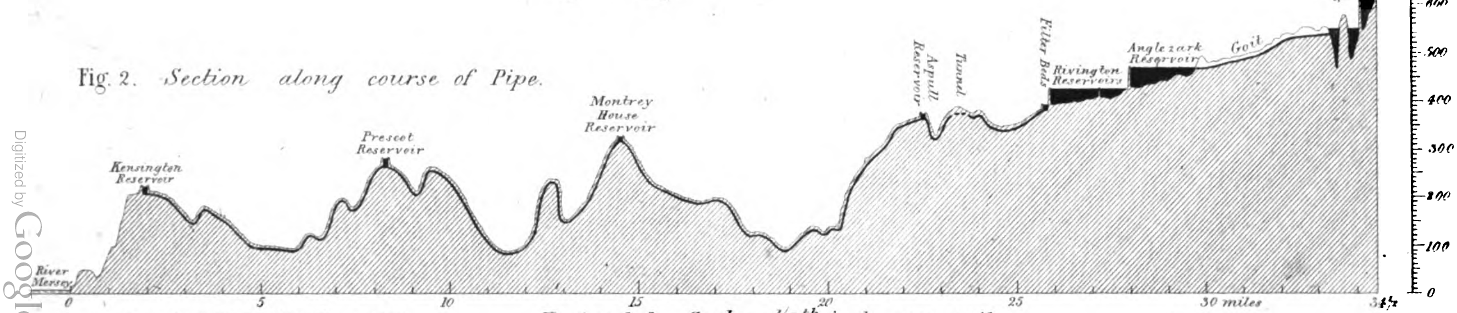


Fig. 2. Section along course of Pipe.

Horizontal Scale 1/5th inch per mile.

(Proceedings Inst. M.E. 1863. Page 167.)

LIVERPOOL WATER WORKS.

Self-acting Gauge on Goit.

Fig. 5. *Section of Outlet Orifice* **B.**
Scale 1/4th.

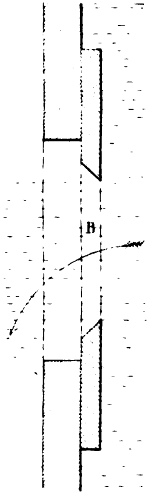


Fig. 3.
Longitudinal Section.

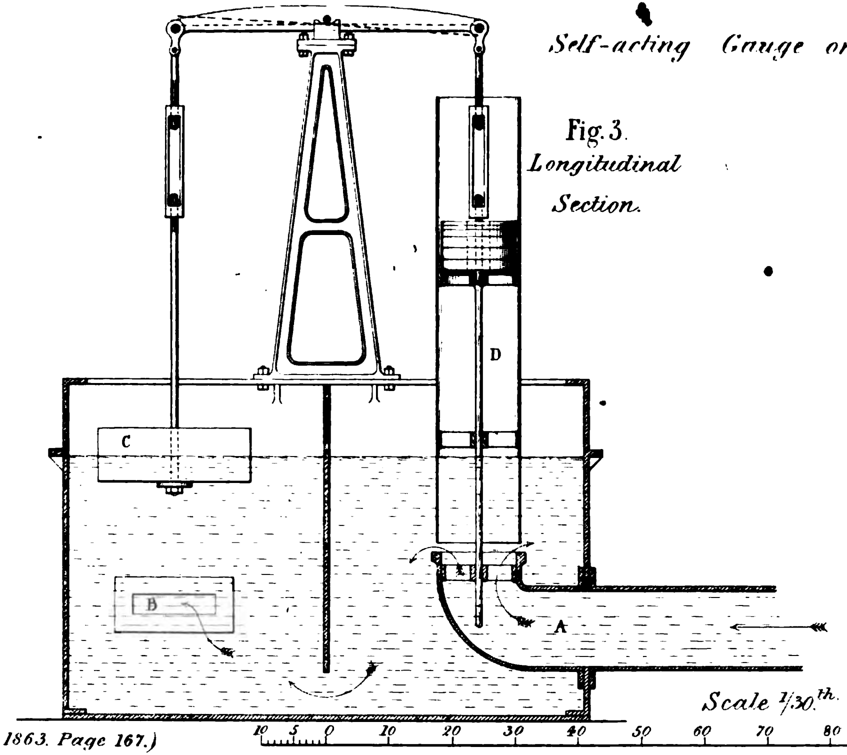
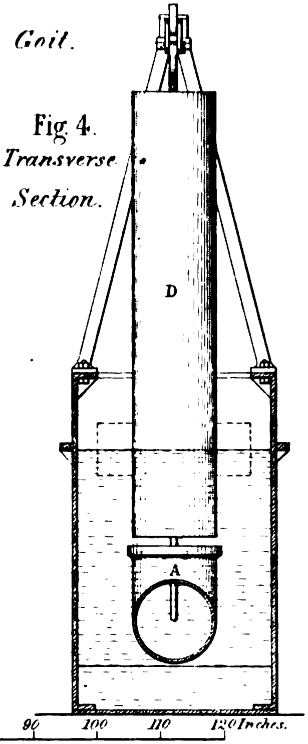


Fig. 4.
Transverse Section.



(Proceedings Inst. M.E. 1863. Page 167.)

LIVERPOOL WATER WORKS. *Plate 46.*

Float Valve at upper end of tunnel.

Fig. 6. *Vertical Section.*

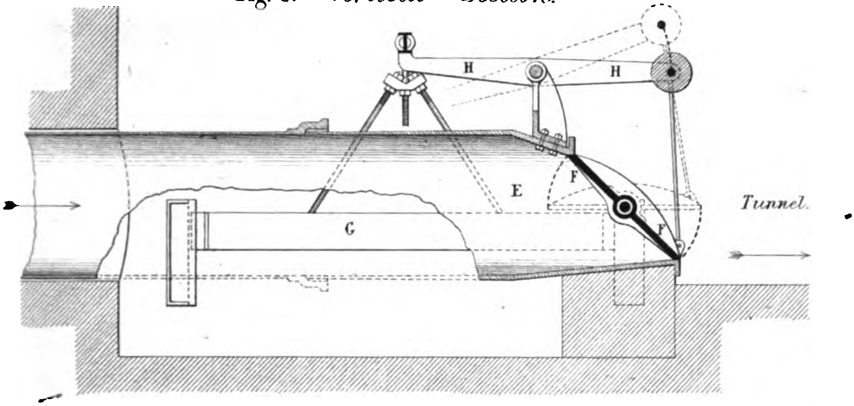
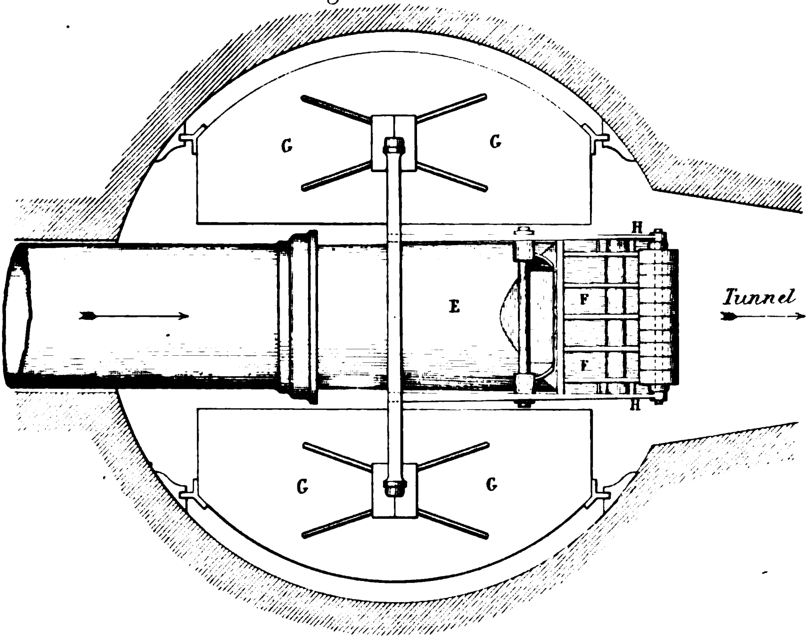


Fig. 7. *Plan.*



Scale 1/60.th

(Proceedings Inst. M.E. 1863. Page 167.)

LIVERPOOL WATER WORKS.

Self-acting Shut-Off Valve.

Fig. 8. *Vertical Section.*

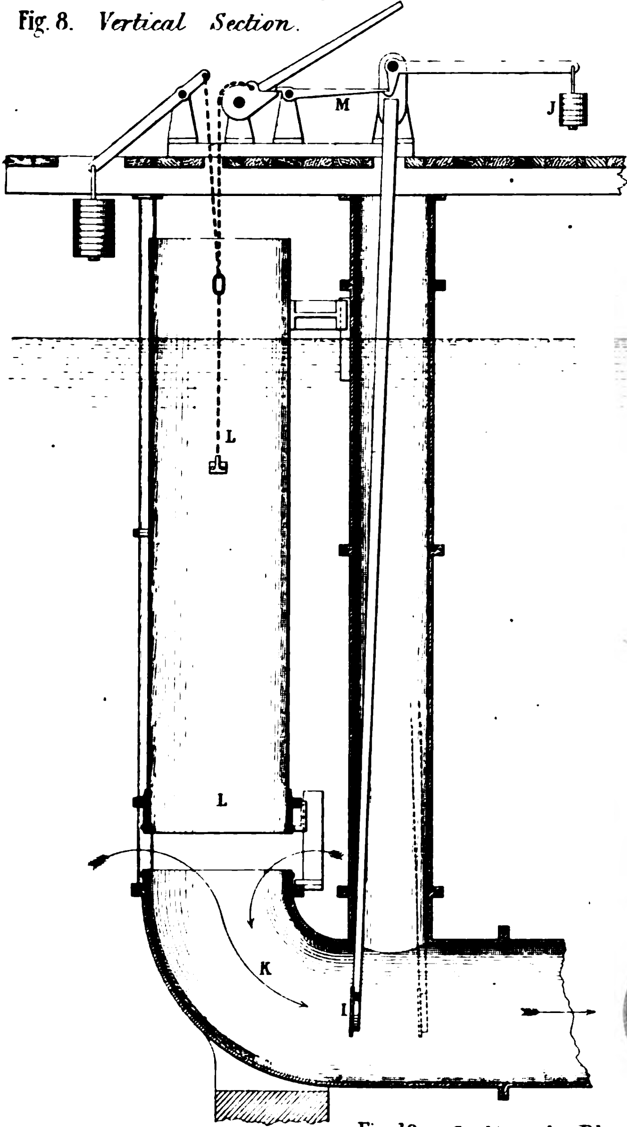


Fig. 9.

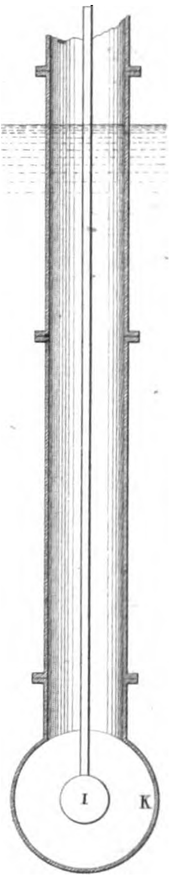
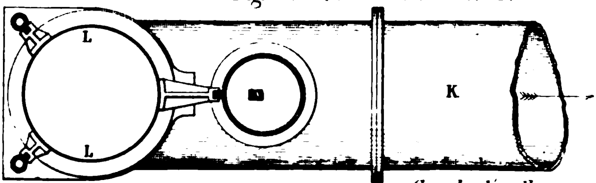


Fig. 10. *Sectional Plan.*



(Proceedings Inst. M.E. 1863. Page 167.)

Scale 1/60th.

0 5 10 15 Feet.

LIVERPOOL WATER WORKS. *Plate 48.*

Fig. 11. *Elevation of Reflux Valve.*

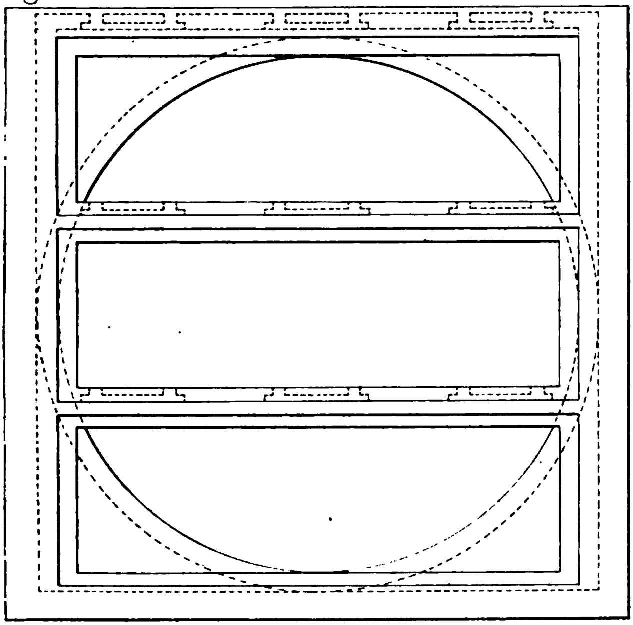


Fig. 12. *Vertical Section.*

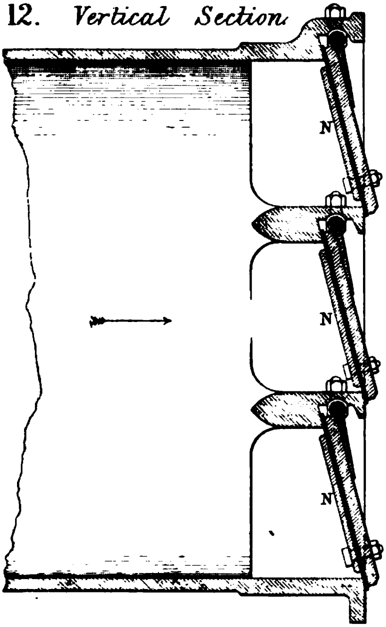
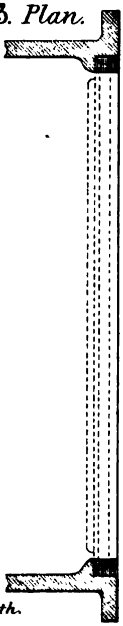
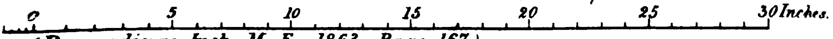


Fig. 13. *Plan.*



Scale 1/16.th



(Proceedings Inst. M. E. 1863. Page 167.)

LIVERPOOL WATER WORKS. *Plate 49.*

Self-acting Throttle Valve in Main.

Fig. 14. *Side Elevation.*

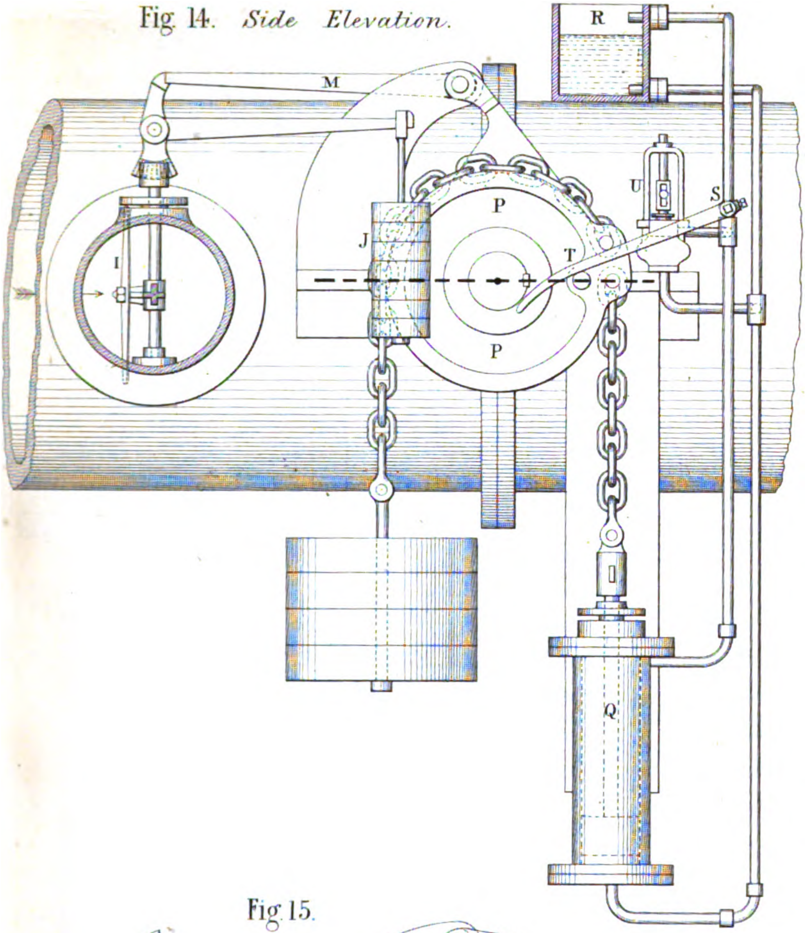
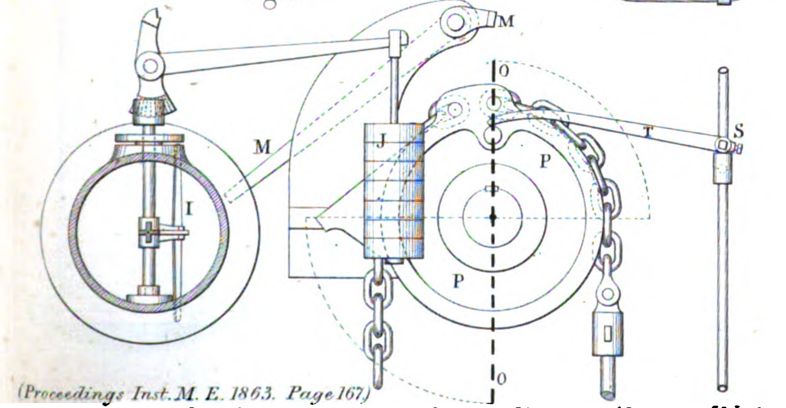


Fig. 15.



(Proceedings Inst. M. E. 1863. Page 167.)

Scale 1/20th 10 5 0 10 20 30 40 50 *Inches.*

LIVERPOOL WATER WORKS. Plate 50.

Self-acting Throttle Valve in Main.

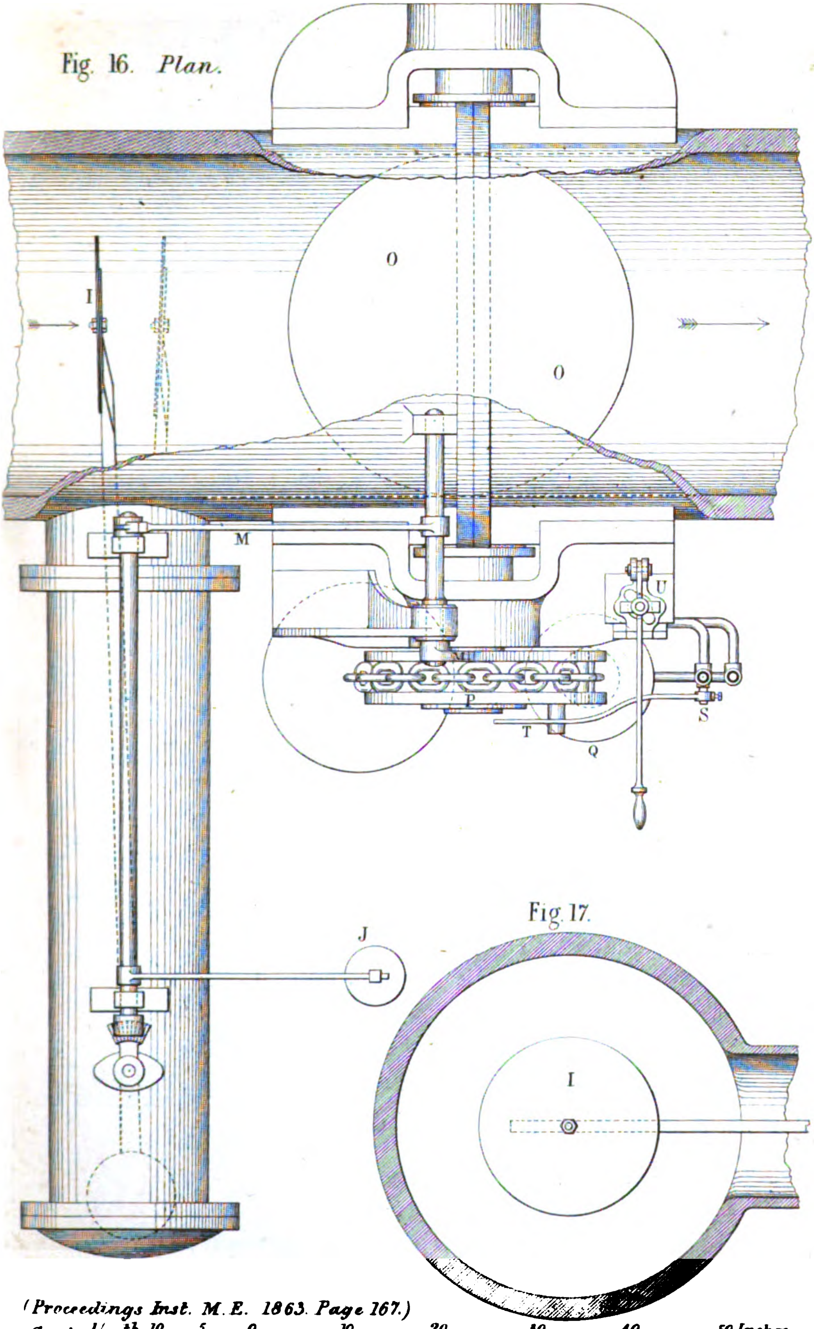


Fig. 16. *Plan.*

Fig. 17.

(Proceedings Inst. M. E. 1863. Page 167.)

Scale 1/20th. 10 5 0 10 20 30 40 50 *Inches.*

LIVERPOOL WATER WORKS.

Plate 51.

Escape Valve on Main.

Fig. 18. *Vertical Section.*

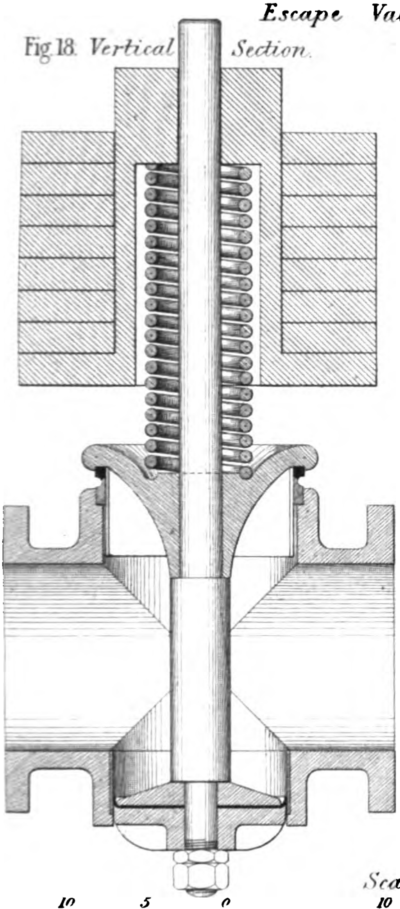
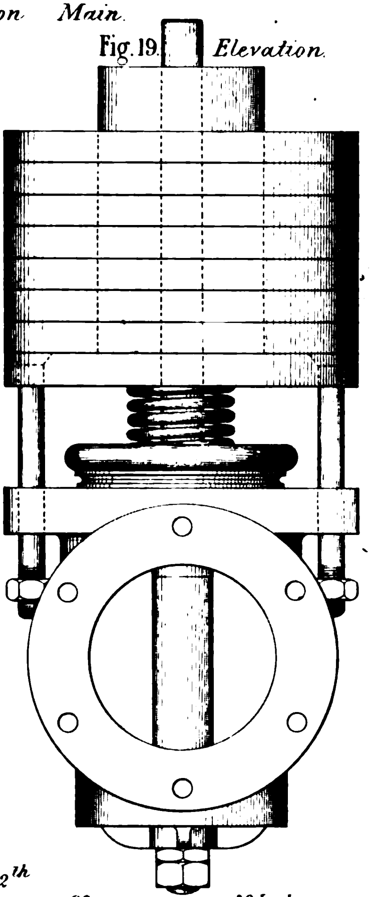


Fig. 19. *Elevation.*



Sections of Joints of Main. Scale one quarter full size.

Fig. 20. *Ordinary Lead Joint of 44 inch main.*

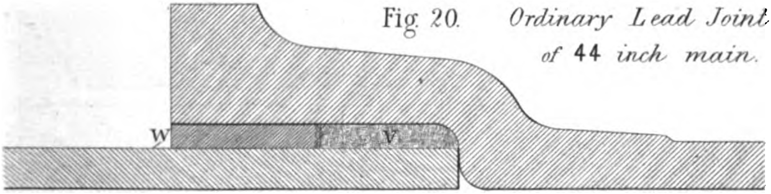
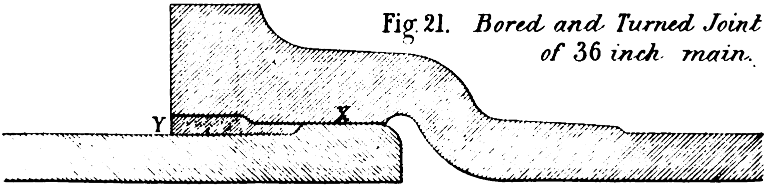


Fig. 21. *Bored and Turned Joint of 36 inch main.*



(Proceedings Inst. M. E. 1863. Page 167.)

LIVERPOOL WATER WORKS.

Plate 52.

Indicator Diagrams from Pumping Engines.

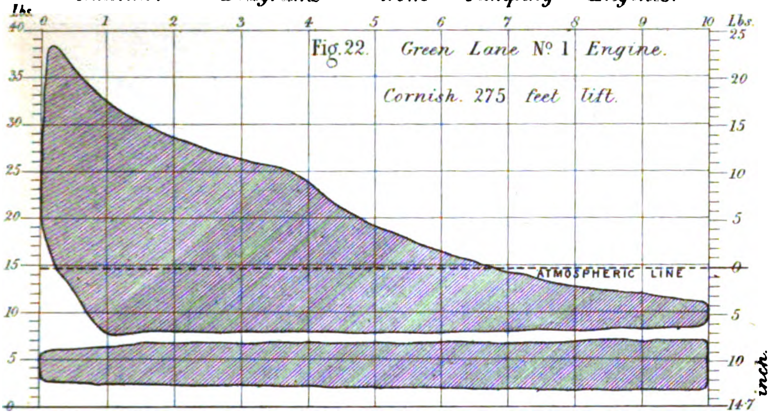


Fig. 22. *Green Lane* No 1 *Engine.*

Cornish. 275 feet lift.

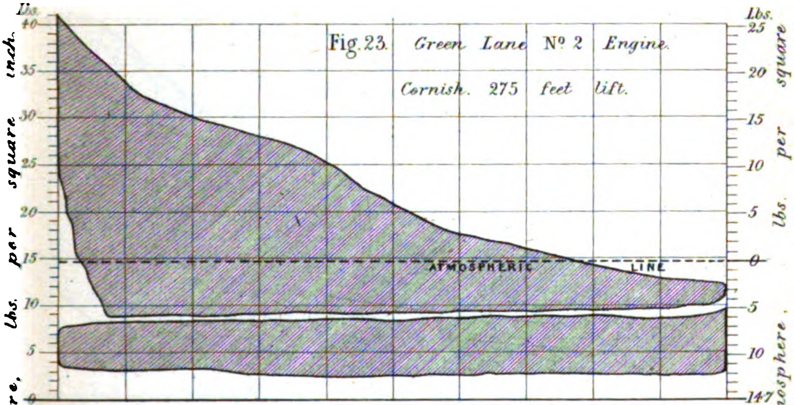


Fig. 23. *Green Lane* No 2 *Engine.*

Cornish. 275 feet lift.

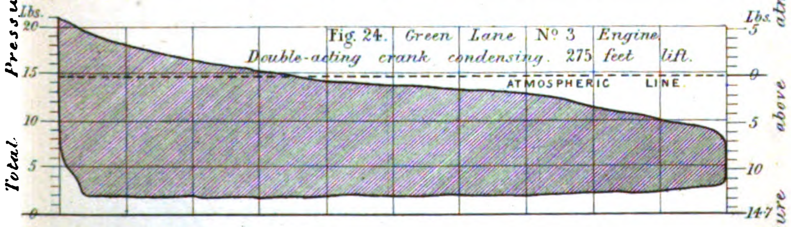


Fig. 24. *Green Lane* No 3 *Engine.*

Double-acting crank condensing. 275 feet lift.

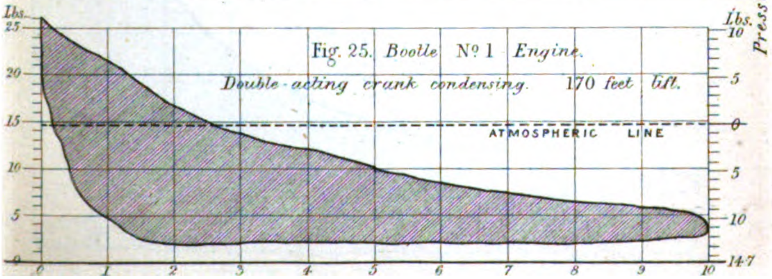


Fig. 25. *Bootle* No 1 *Engine.*

Double-acting crank condensing. 170 feet lift.

(Proceedings Inst. M.E. 1863. Page 167.)

LIVERPOOL WATER WORKS.

Plate 53.

Indicator Diagrams from Pumping Engines.

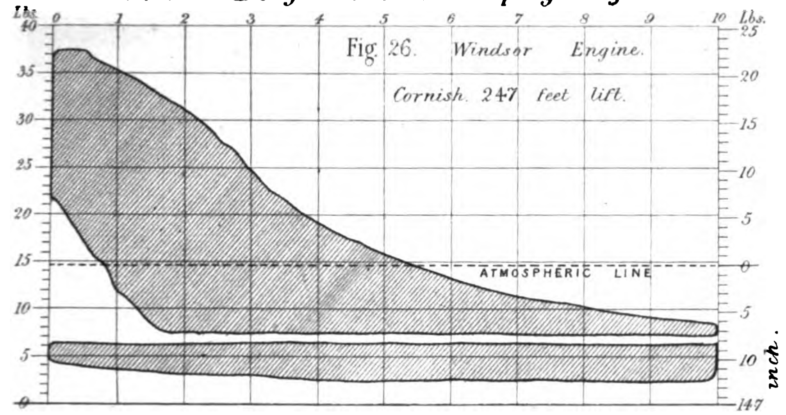


Fig. 26. *Windsor Engine.*

Cornish. 247 feet lift.

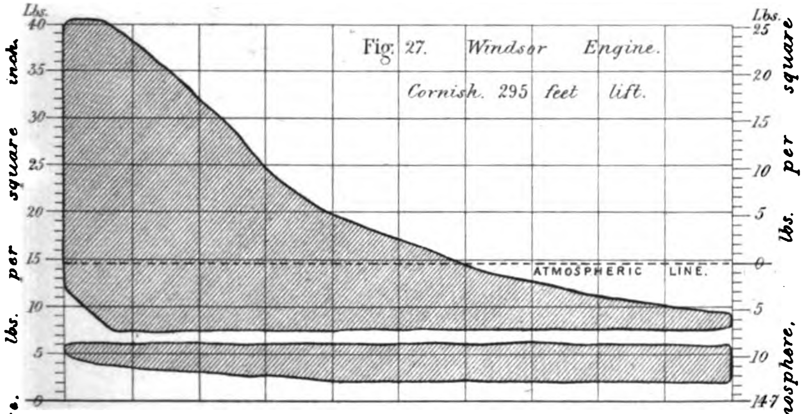


Fig. 27. *Windsor Engine.*

Cornish. 295 feet lift.

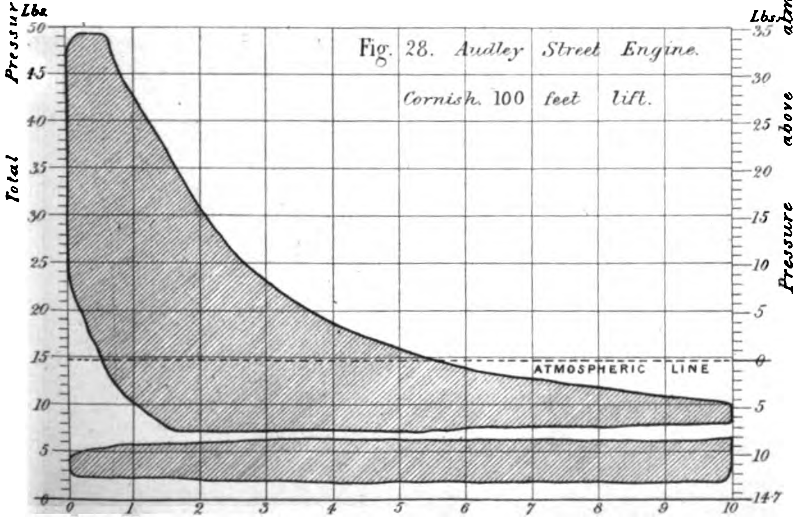
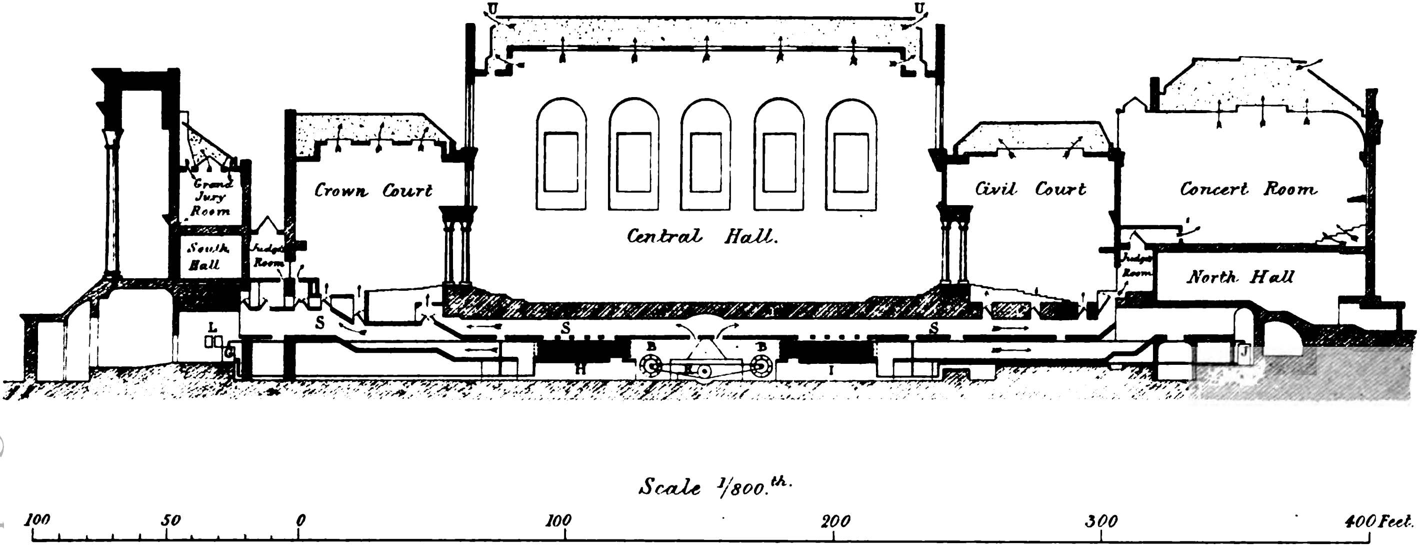


Fig. 28. *Audley Street Engine.*

Cornish. 100 feet lift.

(Proceedings Inst. M.E. 1863. Page 167.)

Fig. 1. *Longitudinal Section of St. George's Hall, Liverpool.*



MECHANICAL VENTILATION AND WARMING.

Plate 55.

Fig. 2. *Basement Plan of St. George's Hall, Liverpool, at level of Upper Air Channels.*

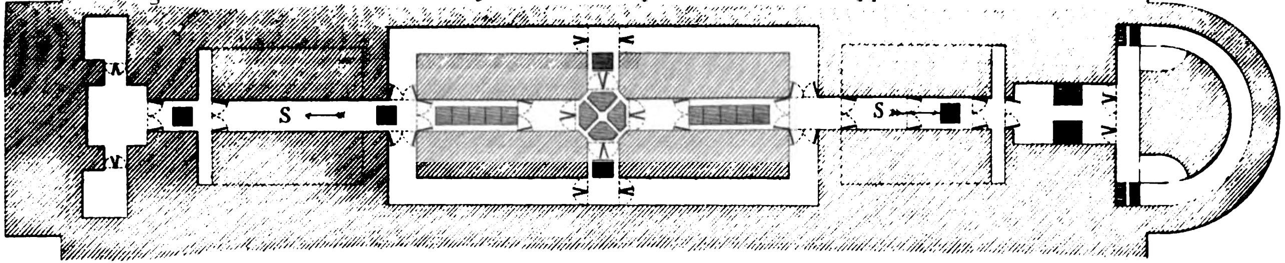
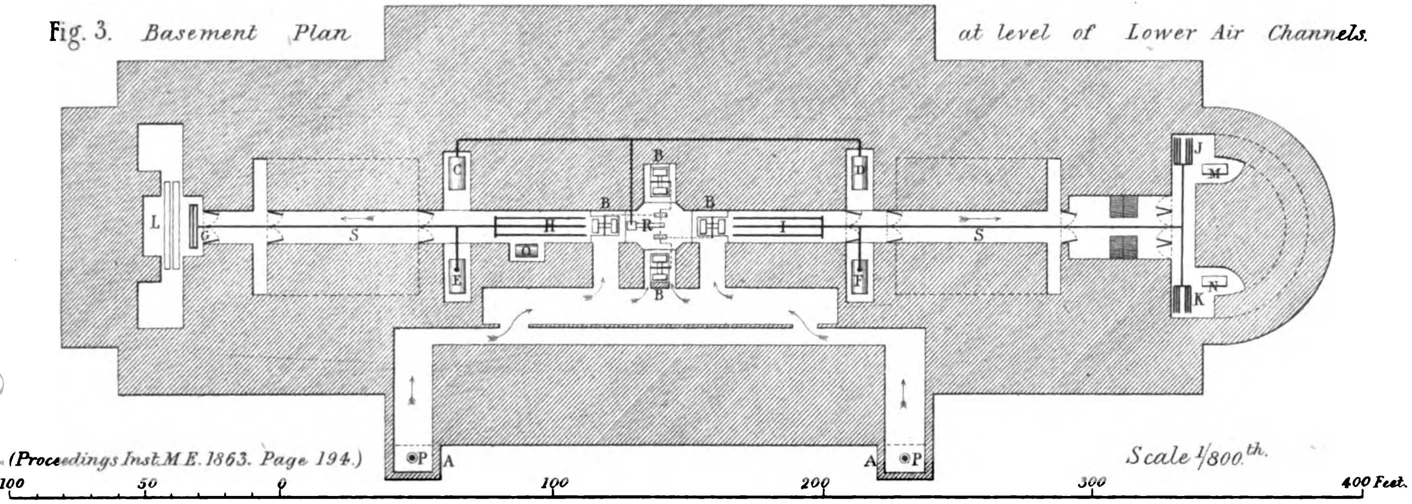
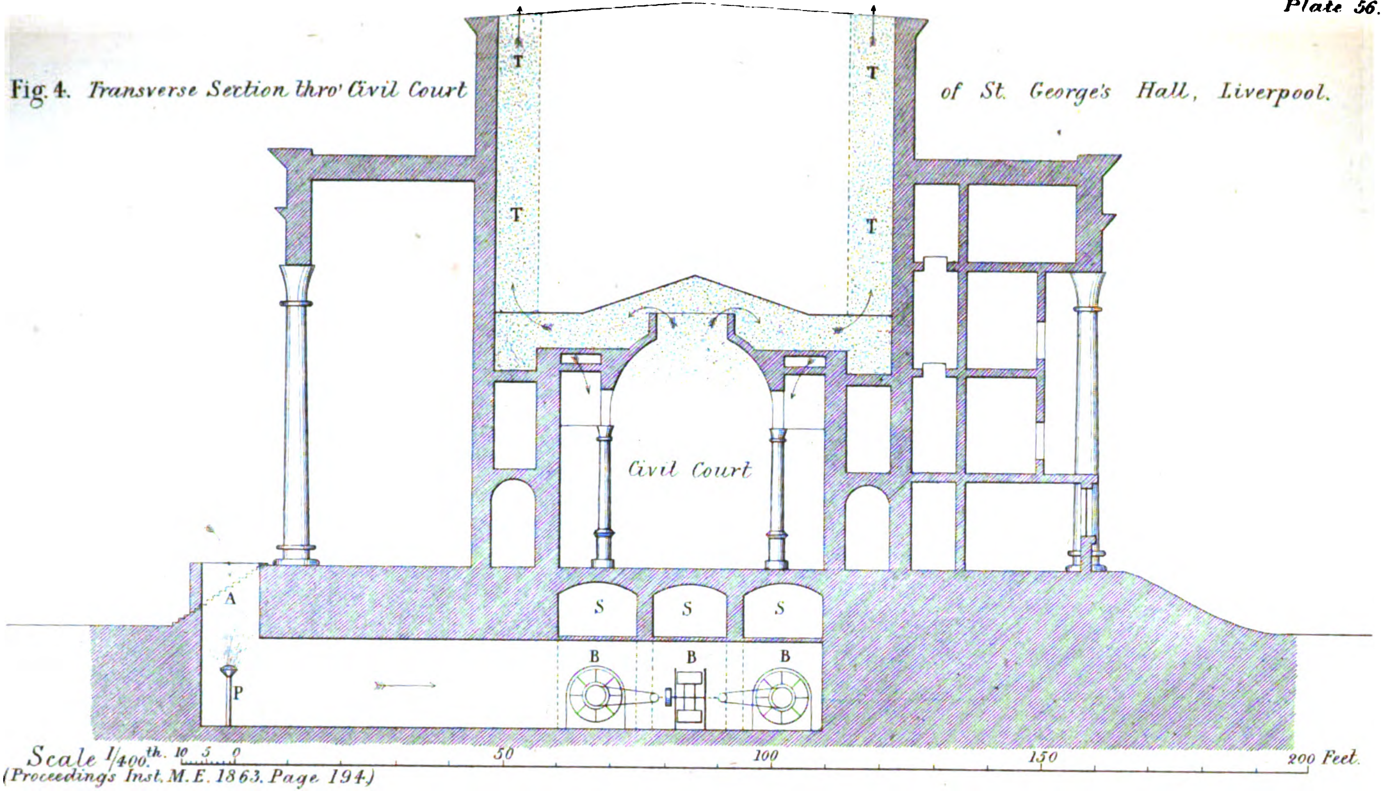


Fig. 3. *Basement Plan at level of Lower Air Channels.*



(Proceedings Inst. M. E. 1863. Page 194.)

Fig. 4. *Transverse Section thro' Civil Court of St. George's Hall, Liverpool.*

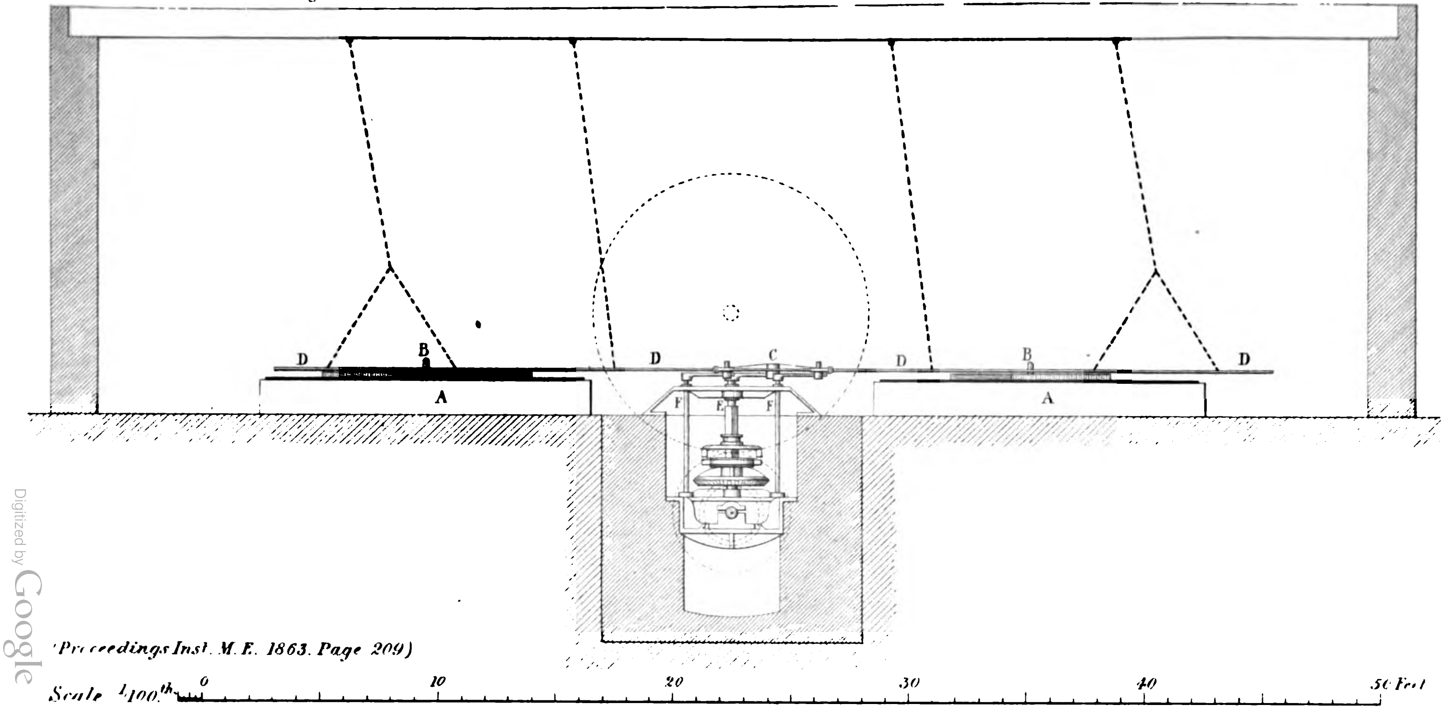


Scale 1/400th.

(Proceedings Inst. M.E. 1863. Page 194.)

PLATE GLASS MACHINERY.

Fig. 1. *Side Elevation of "Fly Frame" Grinding Machine.*



(Proceedings Inst. M. E. 1863. Page 209)

PLATE GLASS MACHINERY.

Fig. 2. *Plan of "Fly Frame" Grinding Machine*

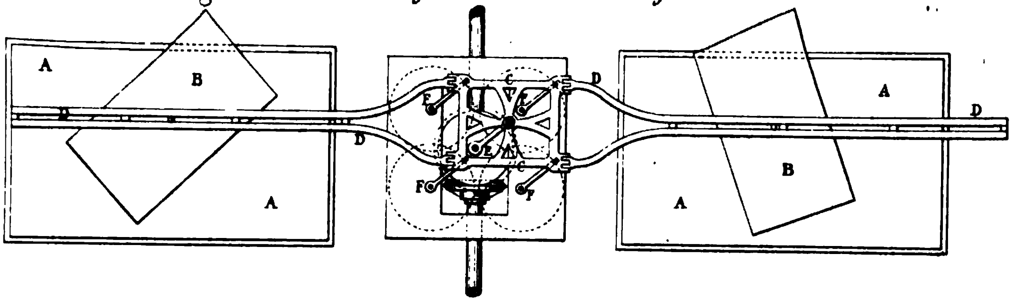
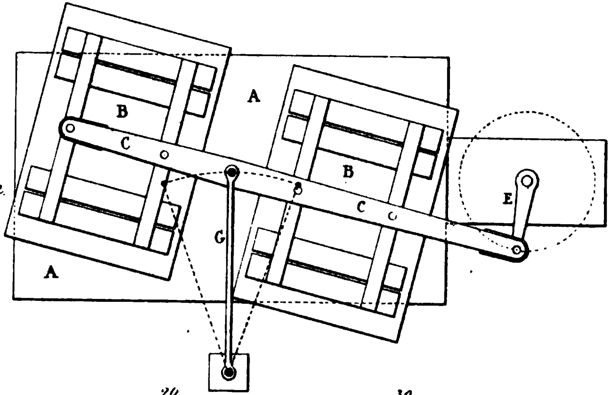


Fig. 3. *Plan of Smoothing Machine.*



(Proceedings Inst. M.E. 1863. Page 209)

Scale 1/100th 0 10 20 30 40 50 Feet

PLATE GLASS MACHINERY.

Polishing Machine

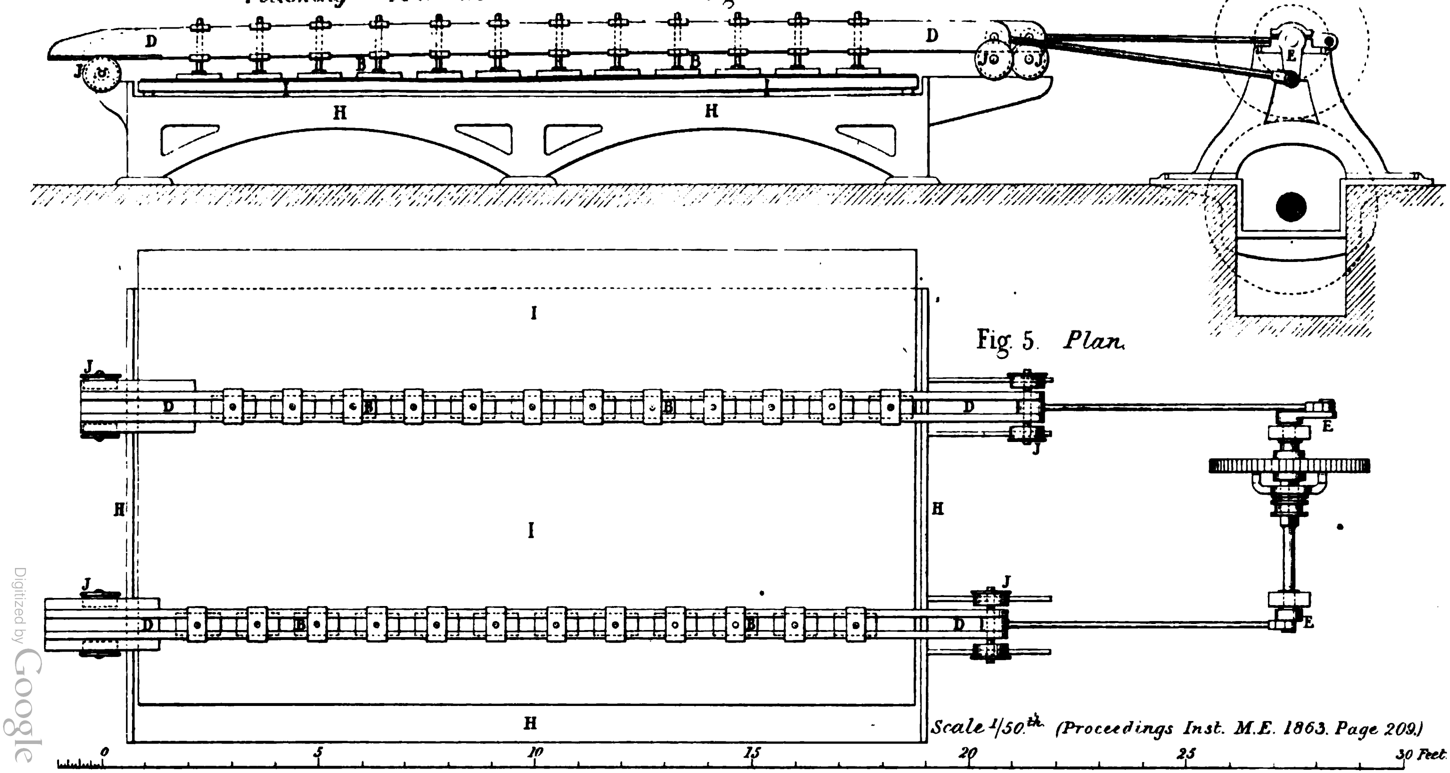


Fig. 4. Side Elevation.

Fig. 5. Plan.

Scale $1/50^{th}$. (Proceedings Inst. M.E. 1863. Page 209.)

Improved Grinding and Smoothing Machine.

Fig. 6. *Elevation*.

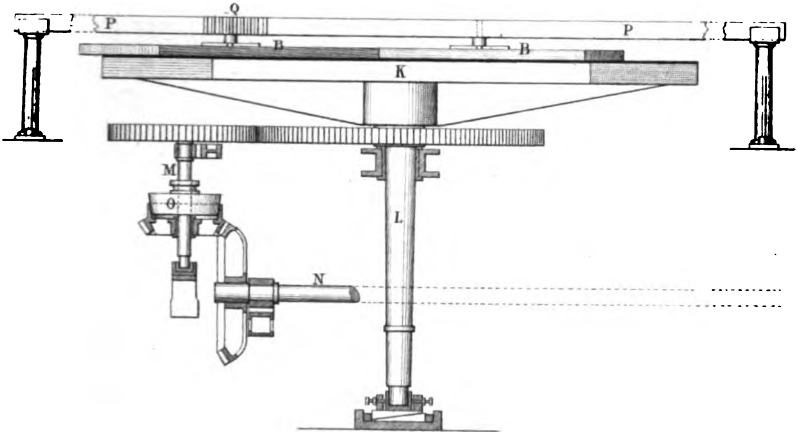
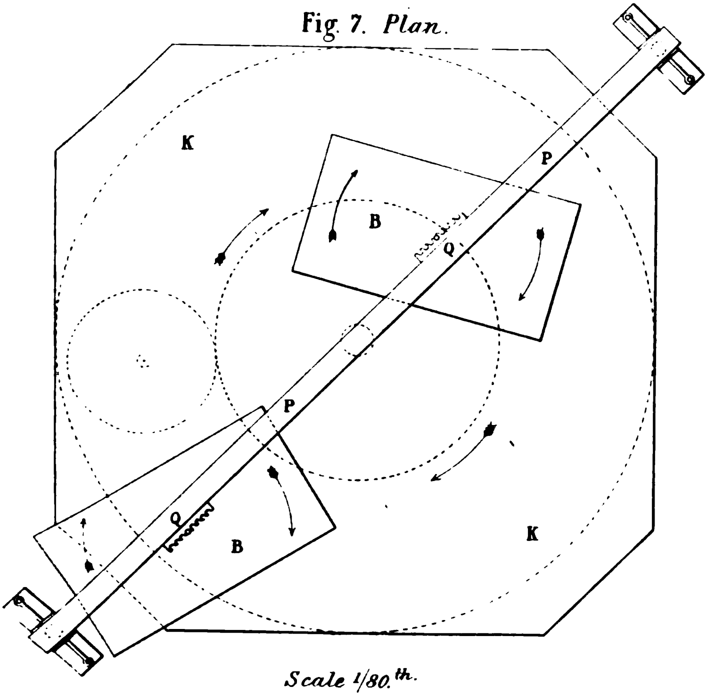
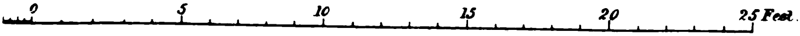


Fig. 7. *Plan*.



Scale 1/80th.



(Proceedings Inst. M.E. 1863. Page 209)

GROSMONT IRON WORKS.

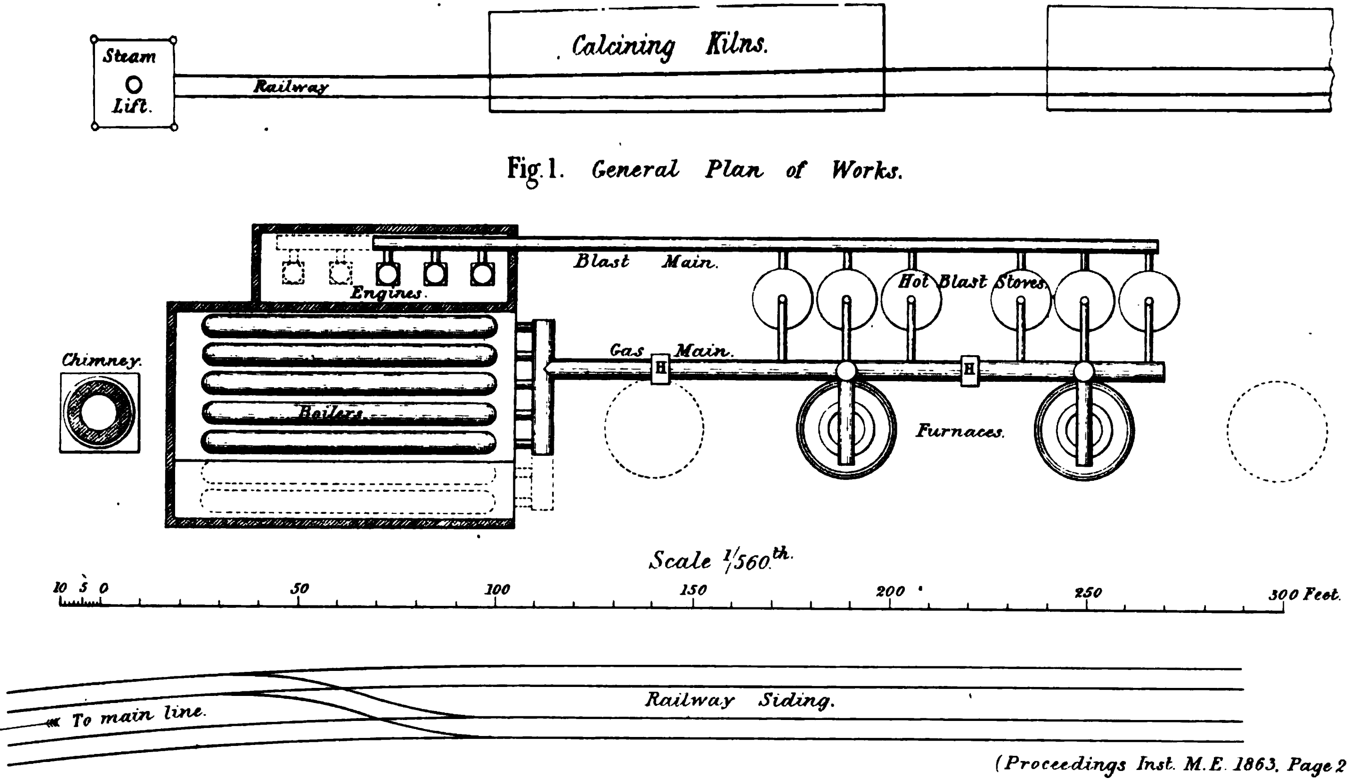
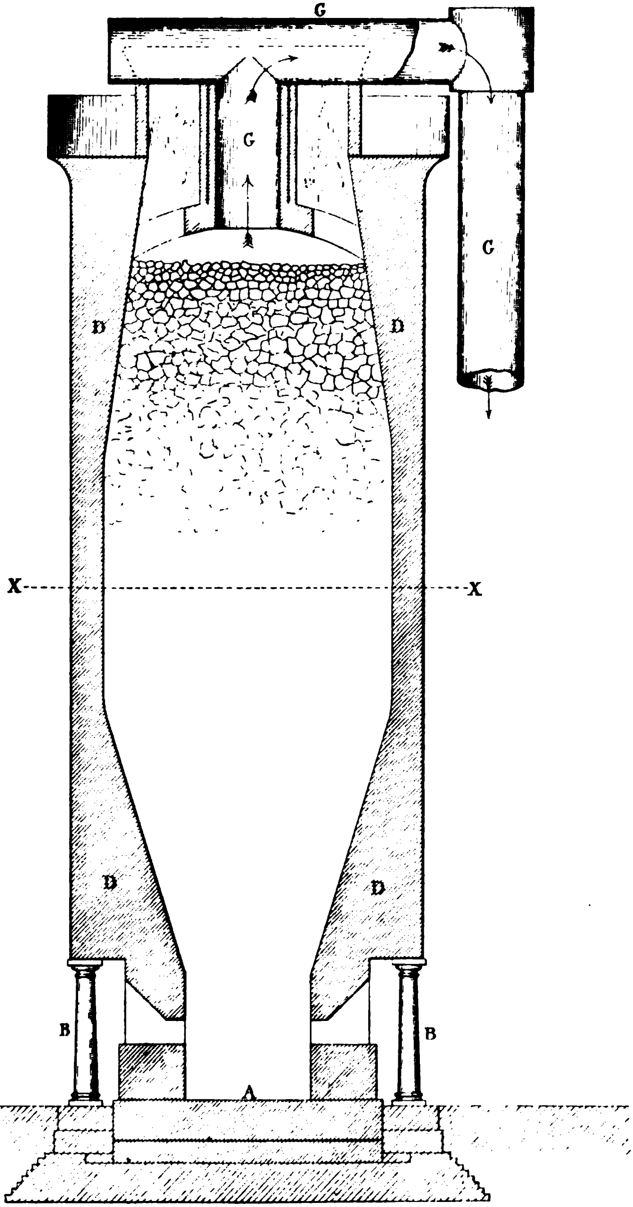


Fig. 1. *General Plan of Works.*

(Proceedings Inst. M.E. 1863. Page 225)

GROSMONT IRON WORKS.

Fig. 2. *Vertical Section of Blast Furnace.*

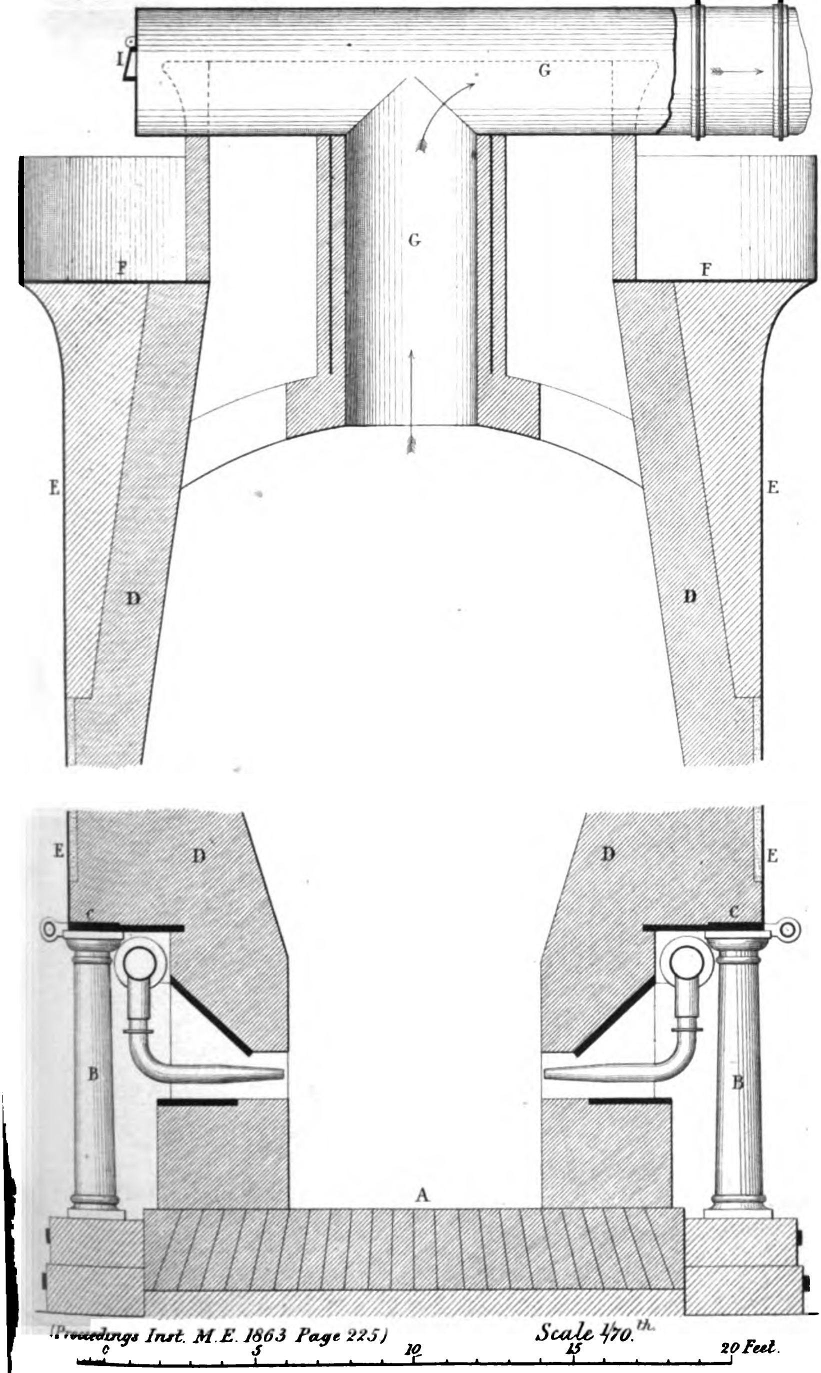


(Proceedings Inst. M.E. 1863 Page 225)

Scale 1/140th.

GROSMONT IRON WORKS. Plate 63.

Fig. 3. *Vertical Section of top and bottom of Blast Furnace.*



(Proceedings Inst. M.E. 1863 Page 225)

Scale 1/70th.

GROSMONT IRON WORKS. *Plate 64.*

Transverse Sections of Blast Furnace.

Fig. 4. *At Tuyeres.*

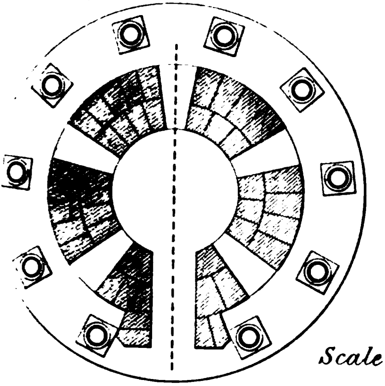
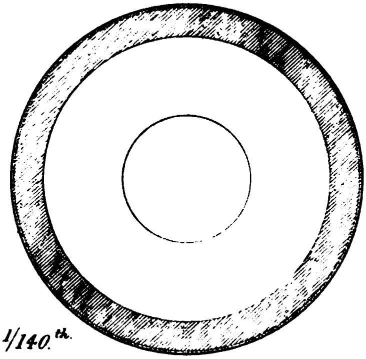


Fig. 8. *At XX (Fig. 2).*



Scale 1/140th.

Fig. 5. *At Tapping Hole.*

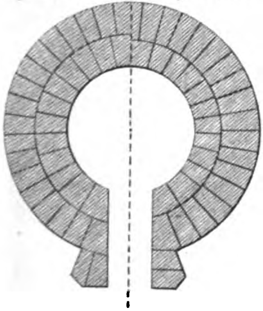


Fig. 9. *Longitudinal Section of Tuyere Pipe.*

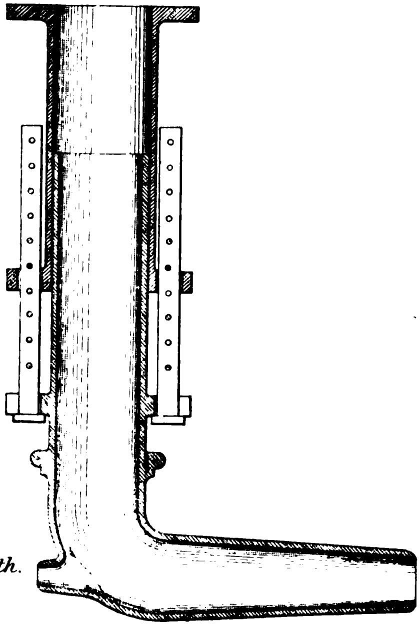


Fig 6. *At Hearth.*

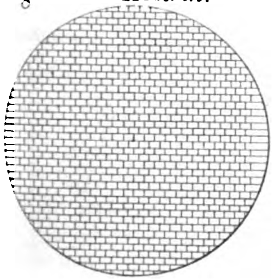


Fig. 7 *Vertical Section of Hearth.*

Scale 1/140th.

Scale 1/12th.

(Proceedings Inst. M.E. 1863. Page 225.)

GROSMONT IRON WORKS.

Hot-Blast Stove.

Plate 65.

Fig. 10. *Vertical Section.*

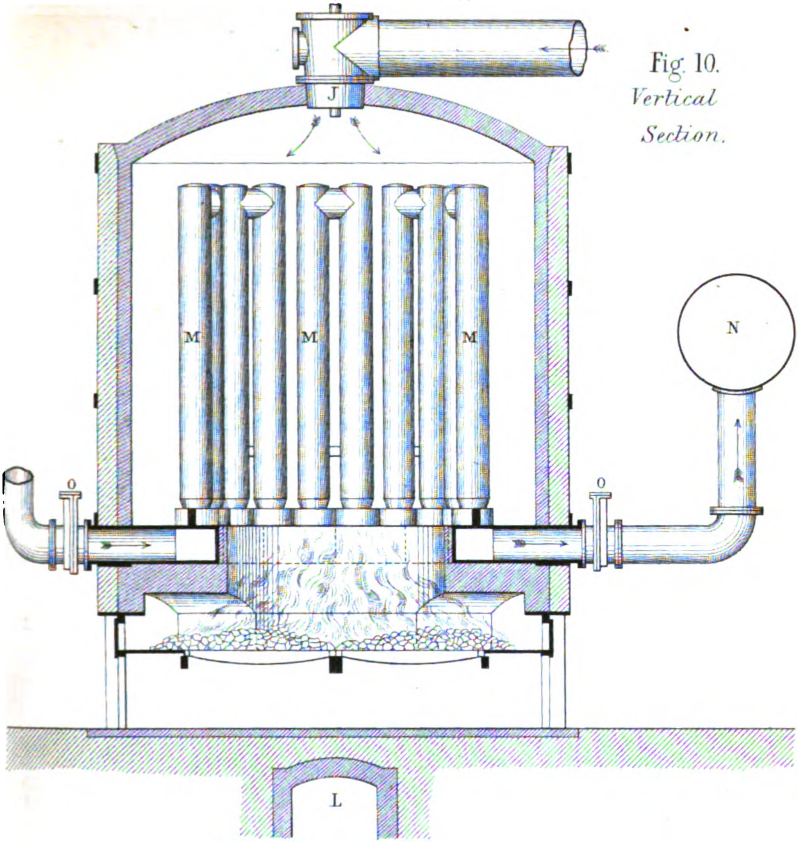
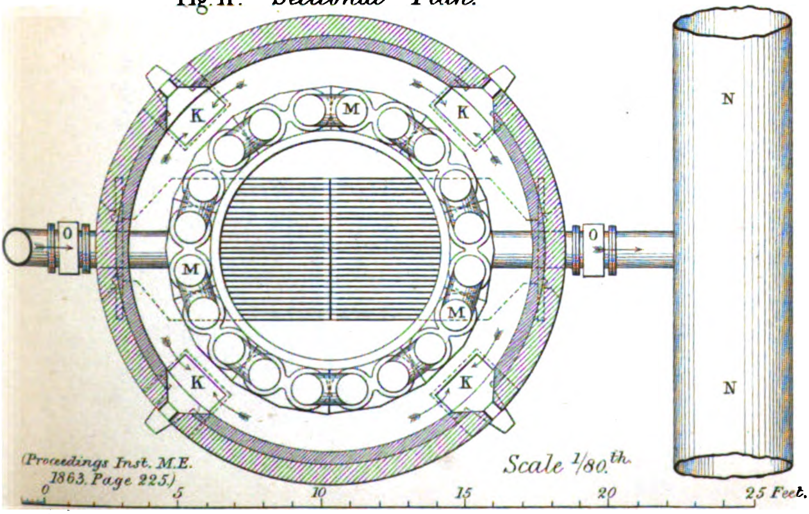


Fig. 11. *Sectional Plan.*

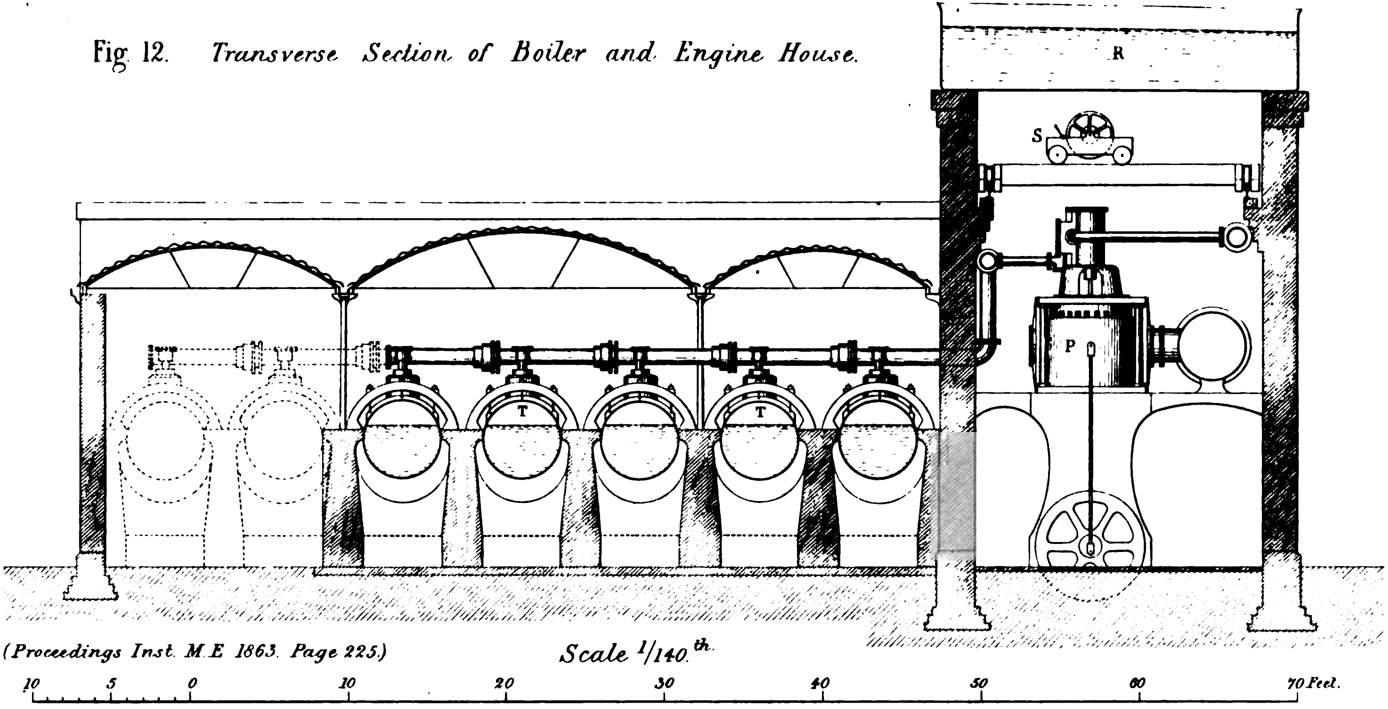


(Proceedings Inst. M.E. 1863. Page 225.)

Scale 1/80th

GROSMONT IRON WORKS.

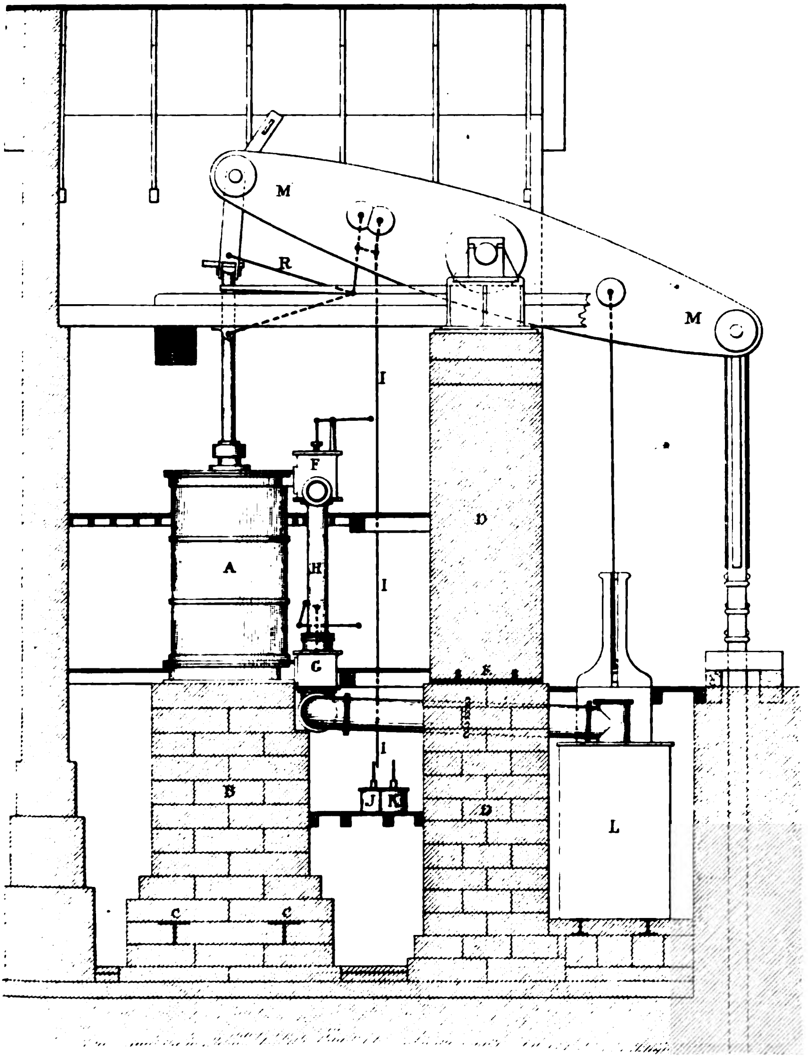
Fig. 12. *Transverse Section of Boiler and Engine House.*



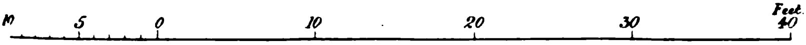
(Proceedings Inst. M.E. 1863. Page 225.)

Scale 1/140th.

Fig. 1. *Side Elevation of Engine.*



Scale 1/150th.



(*Proceedings Inst. M E. 1863. Page 248.*)

CLAY CROSS PUMPING ENGINE.

Plate 68.

Fig. 2. *Longitudinal Section and Elevation of Wrought Iron Beam.*

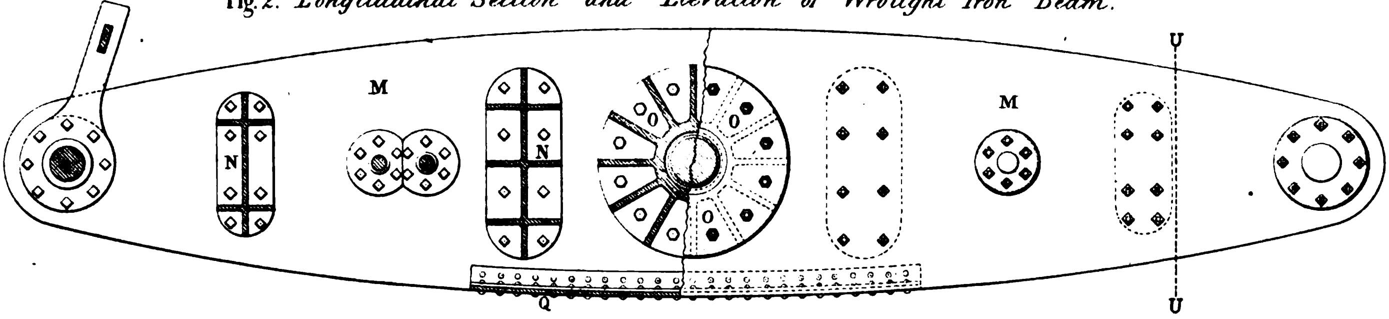
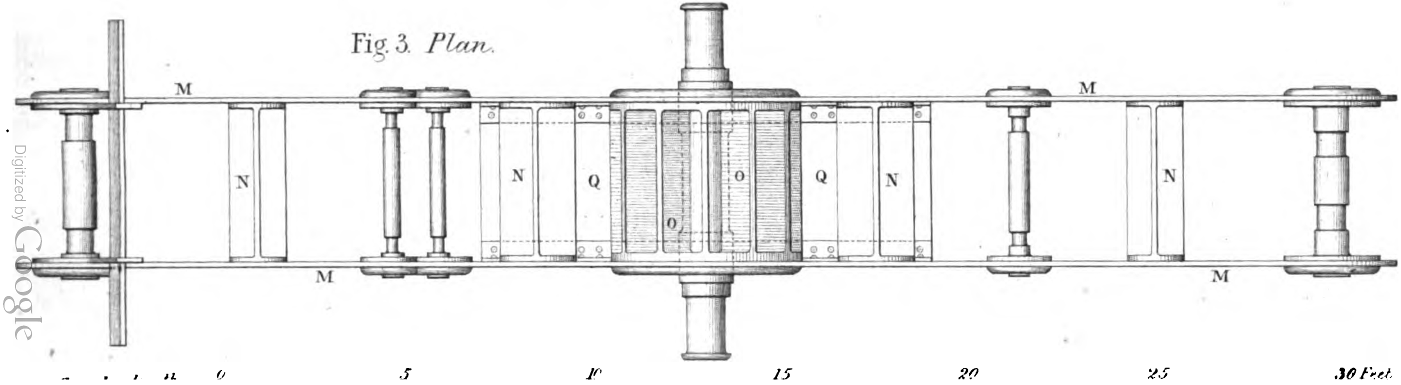


Fig. 3. *Plan.*



CLAY CROSS PUMPING ENGINE. *Plate 69.*

Transverse Sections of Wrought Iron Beam.

Fig. 4. *At Centre.*

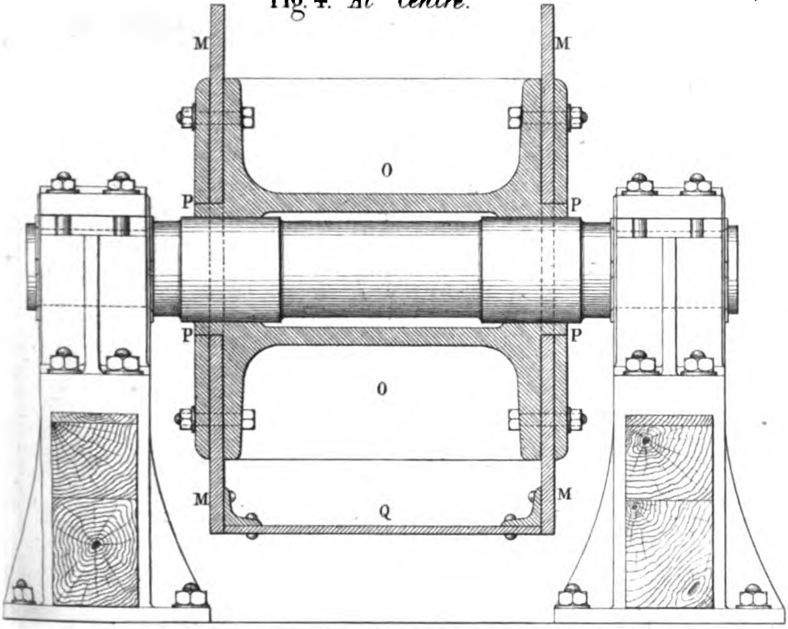


Fig. 5. *At UU (Fig. 2)*

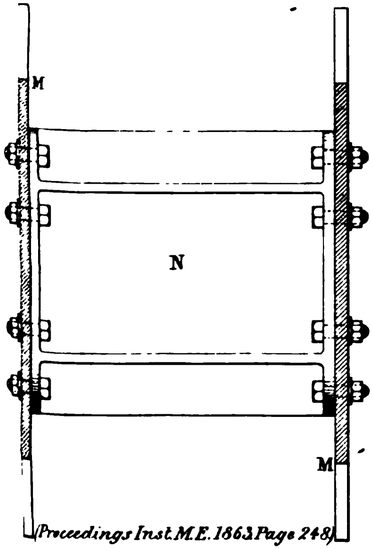
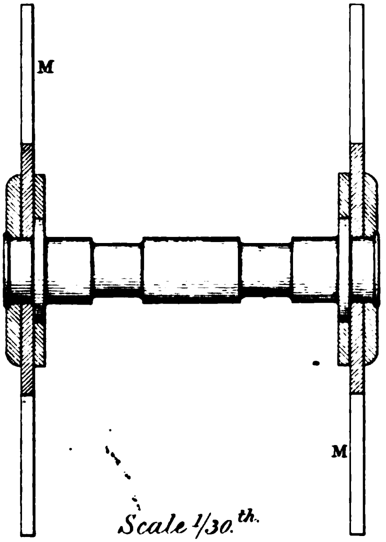


Fig. 6. *At End.*

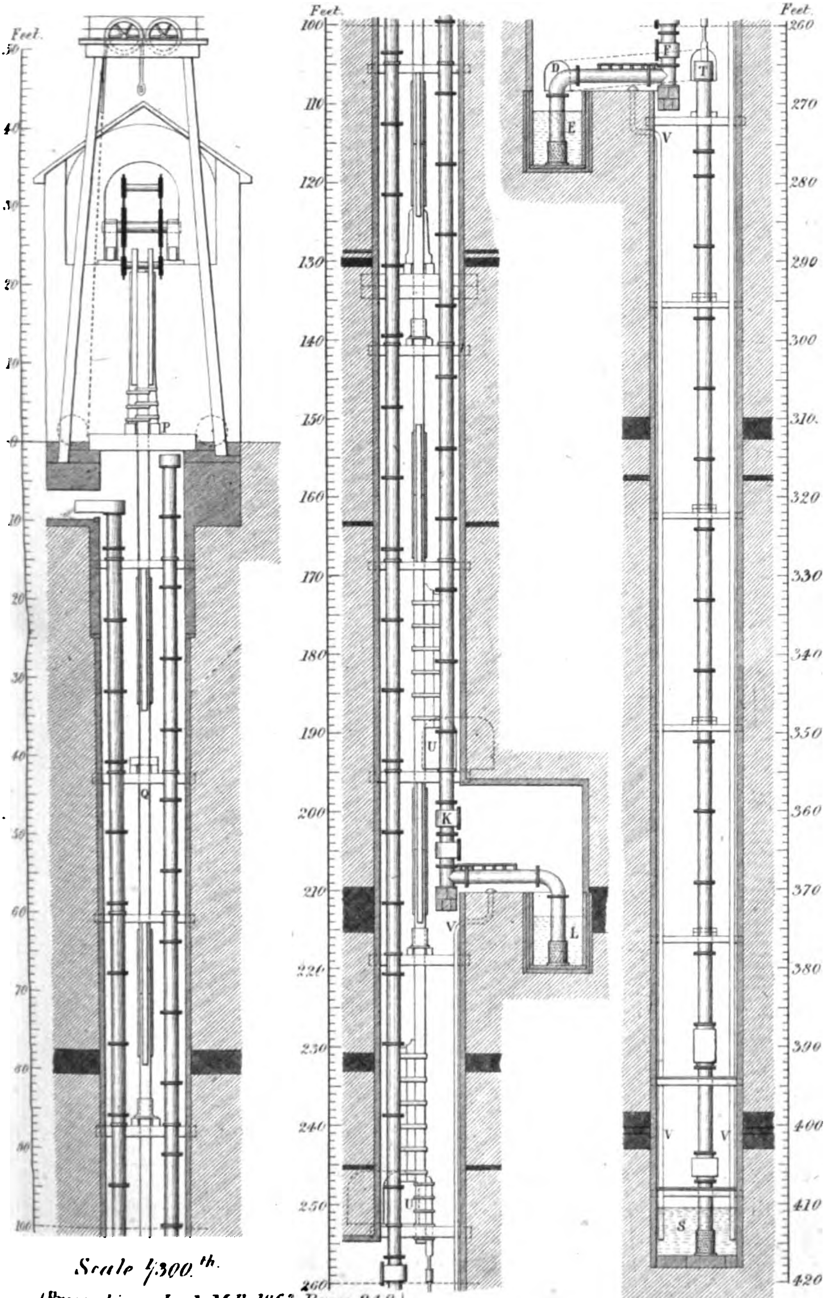


(Proceedings Inst. M.E. 1863 Page 248)

Scale 1/30th.

CLAY CROSS PUMPING ENGINE. *Plate 70.*

Fig. 7. *Vertical Section of Pit.*

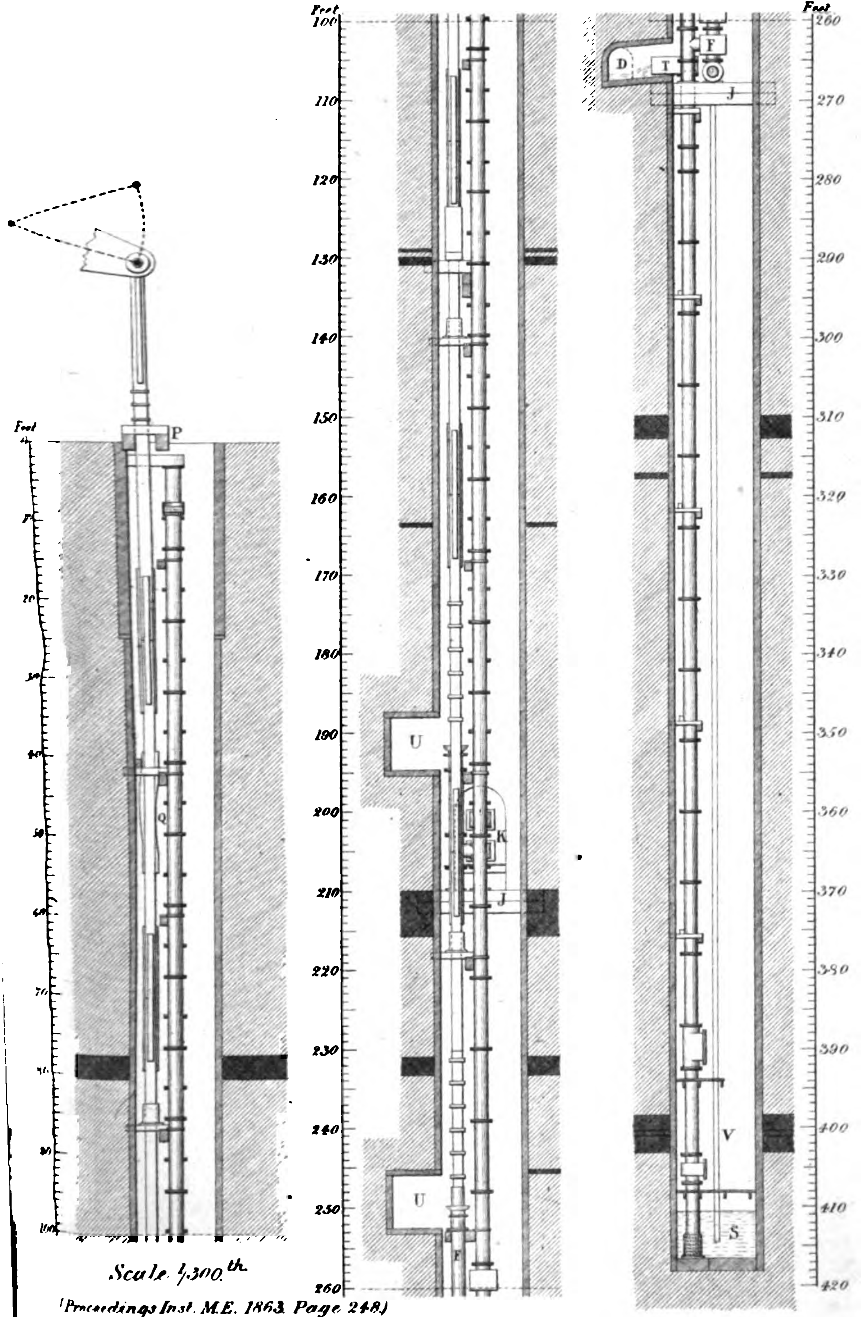


Scale 1/300th.

(Proceedings Inst. M.E. 1863. Page 248.)

CLAY CROSS PUMPING ENGINE. *Plate 71.*

Fig. 8. *Vertical Section of Pit, taken at right angles to Fig. 7.*



Scale 1/300th

(Proceedings Inst. M.E. 1863. Page 248.)

CLAY CROSS PUMPING ENGINE. *Plate 72.*

Fig. 9. *Sectional Plan of Pit at Upper Plunger Pump.*

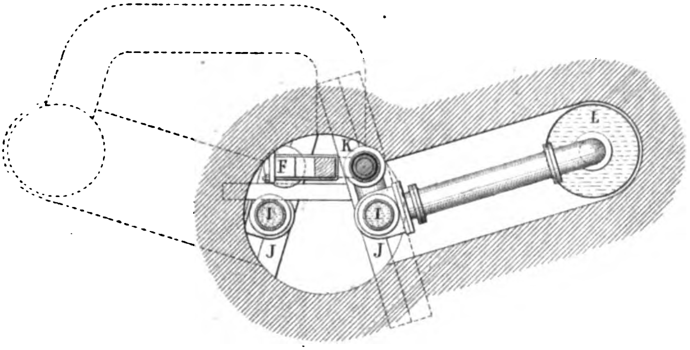


Fig. 10. *Sectional Plan of Pit at Lower Plunger Pump.*

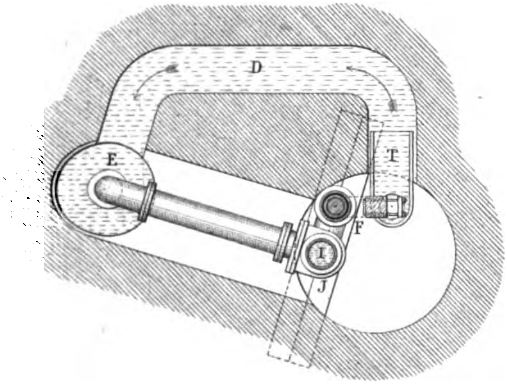
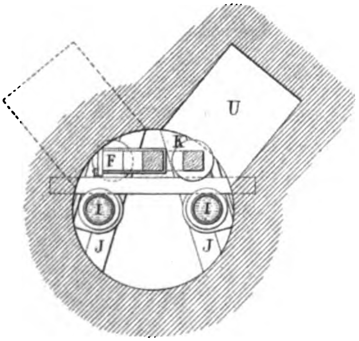
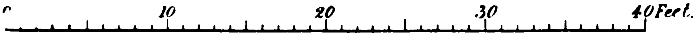


Fig. 11. *Sectional Plan of Pit at Gland of Plunger Pump.*



Scale 1/150th.



(Proceedings Inst. M.E. 1863. Page 248.)

CLAY CROSS PUMPING ENGINE. *Plate 73.*

Bucket Pump.

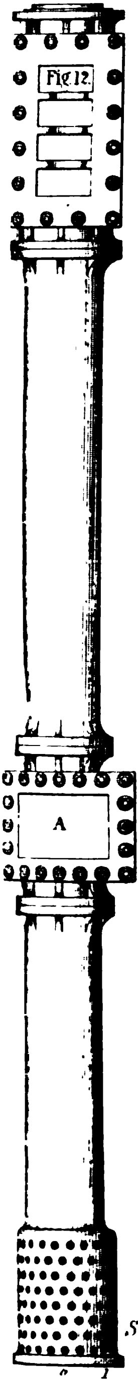


Fig 12.

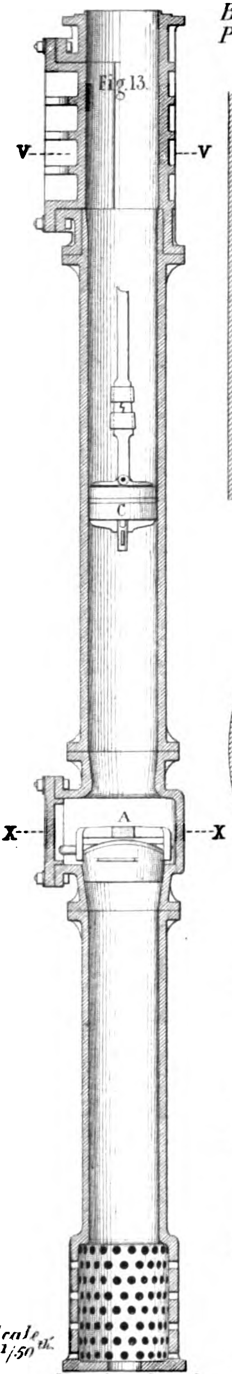


Fig 13.

Scale 1/50th.

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 Feet.

Fig. 16. *Section of Bucket.*

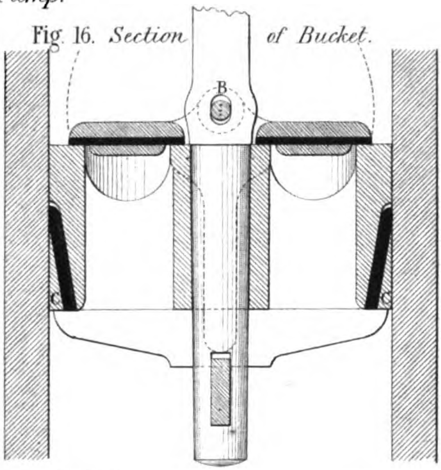
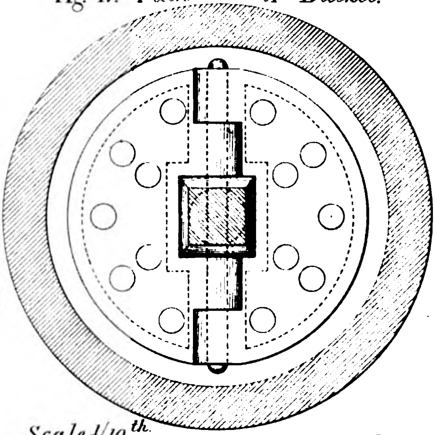


Fig. 17. *Plan of Bucket.*



Scale 1/10th.

0 5 10 15 20 *Inches.*

Fig. 14.
Sectional Plan at **VV.**

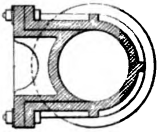
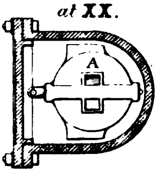


Fig. 15.
Sectional Plan at **XX.**



Scale 1/50th.

(*Proceedings Inst. M.E. 1863. Page 248.*)

CLAY CROSS PUMPING ENGINE. *Plate 74.*

Detail of Pump Clacks, enlarged.

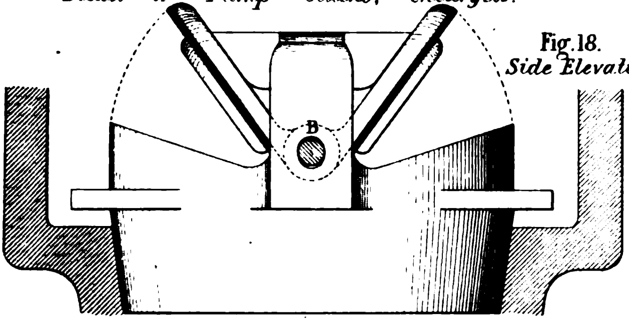


Fig. 18. *Side Elevation.*

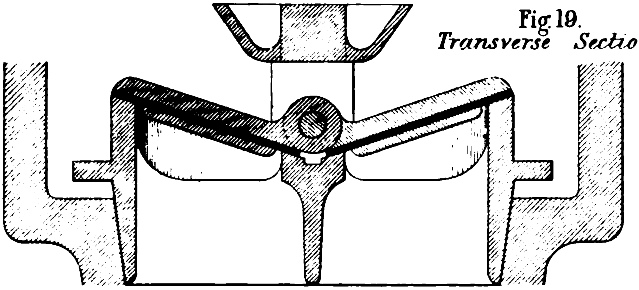


Fig 19. *Transverse Section.*

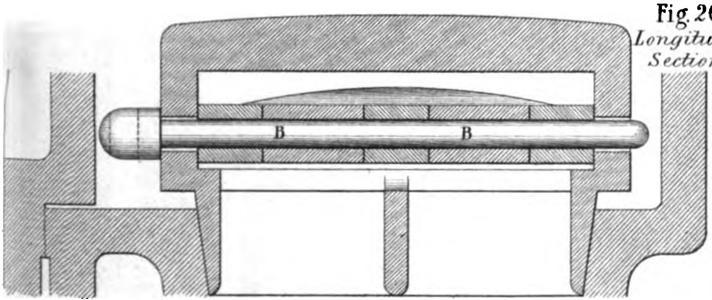


Fig 20. *Longitudinal Section.*

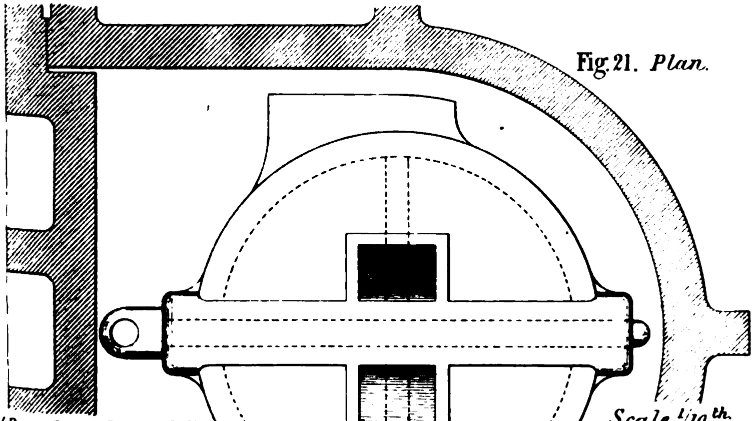


Fig 21. *Plan.*

Scale 1/10th.

10 5 0 10 20 Inches.

(Proceedings Inst. M.E. 1863. Page 248

CLAY CROSS PUMPING ENGINE. Plate 75.

Plunger Pumps.

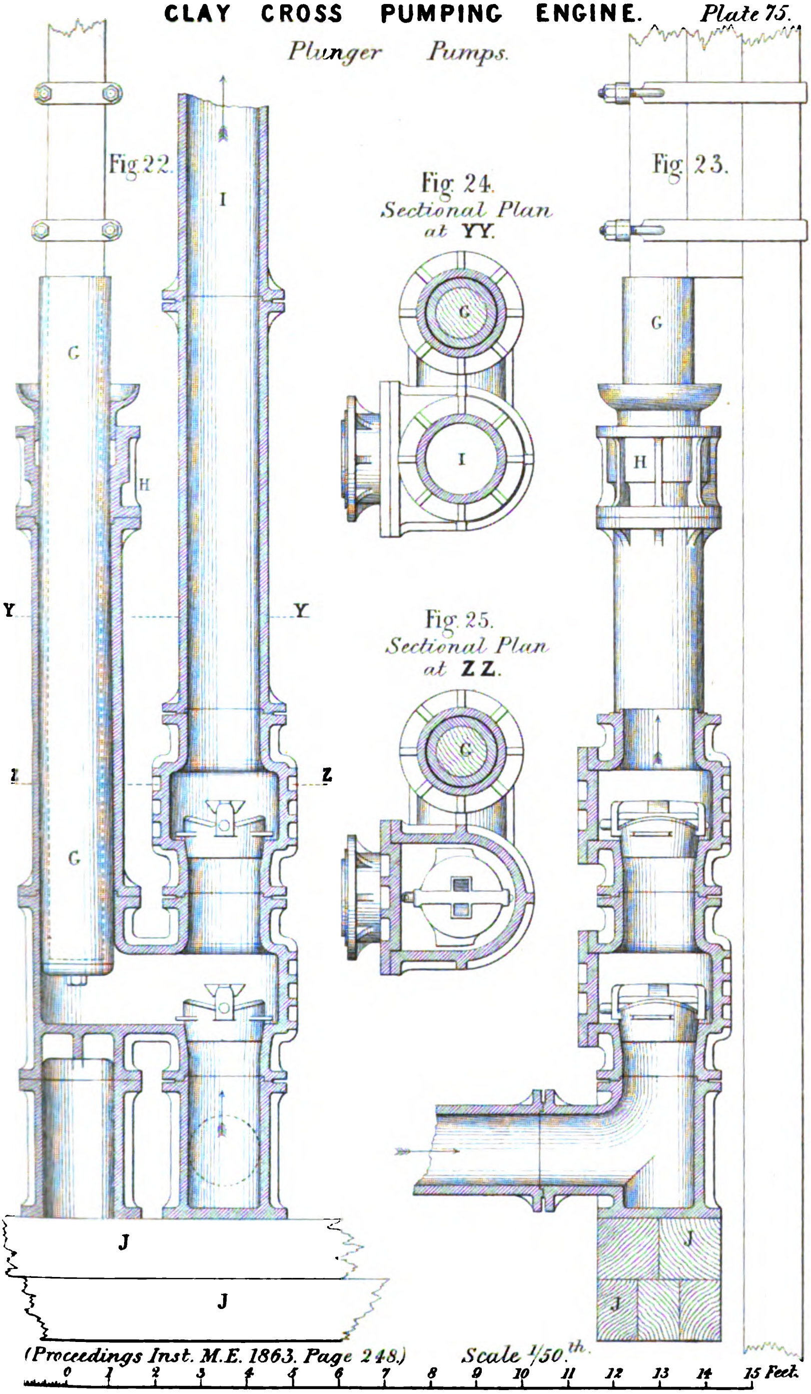


Fig. 22.

Fig. 23.

Fig. 24. Sectional Plan at YY.

Fig. 25. Sectional Plan at ZZ.

(Proceedings Inst. M.E. 1863. Page 248.) Scale 1/50th.

CLAY CROSS PUMPING ENGINE. *Plate 76.*

Joints of 19 inch Rising Mains of Pumps.

Fig. 26. *At bottom of Main.*

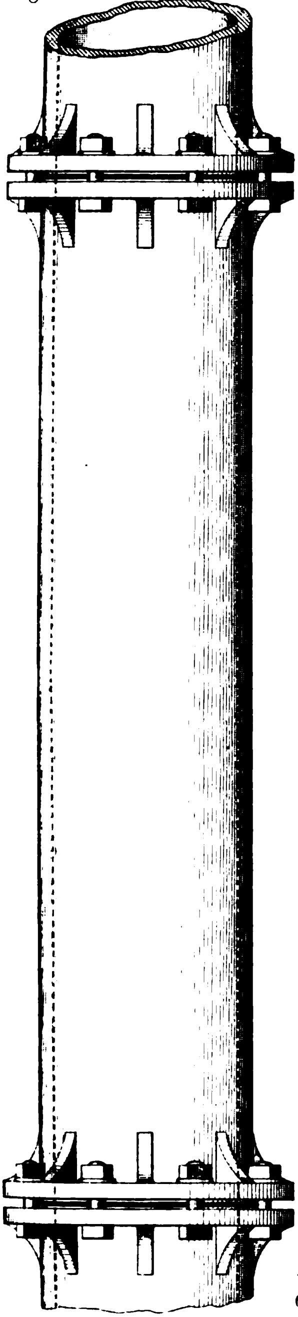


Fig. 27. *At top of Main.*

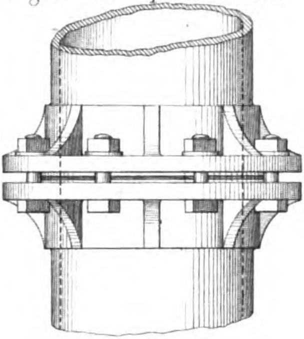


Fig. 29. *Enlarged Section of Joint. Scale 1/4th.*

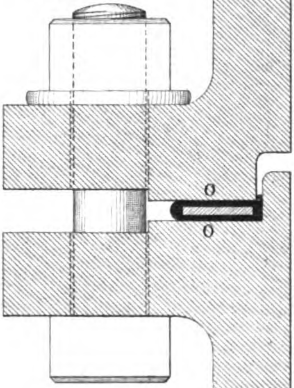
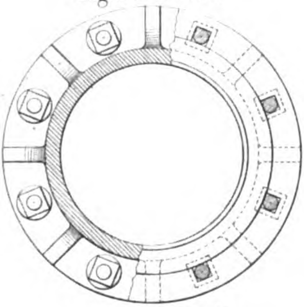


Fig. 28. *Plan.*



Scale 1/20th.

10 5 0 10 20 30 *Inches.*

(Proceedings Inst. M.E. 1863. Page 248.)

CLAY CROSS PUMPING ENGINE.

Plate 77.

Banging Beams and Spear Guides in pit.

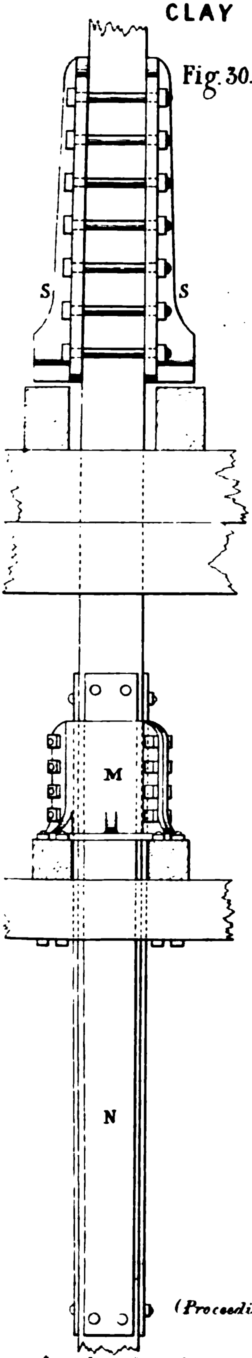


Fig. 30.

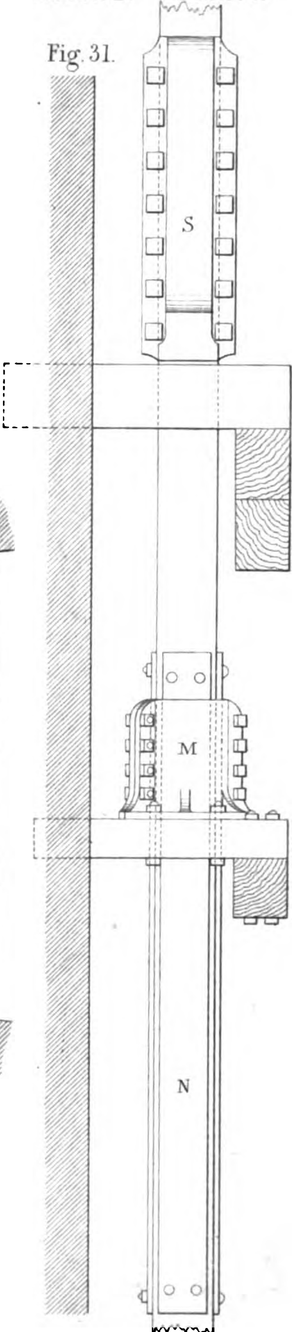


Fig. 31.

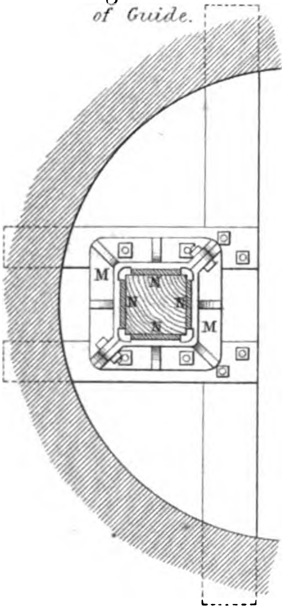


Fig. 32. *Plan of Guide.*

(Proceedings Inst. M.E. 1863. Page 248.)

Scale 1/50th.

Plate 78.

CLAY CROSS PUMPING ENGINE.

Banging Beams at top of Pit.

Fig. 33.

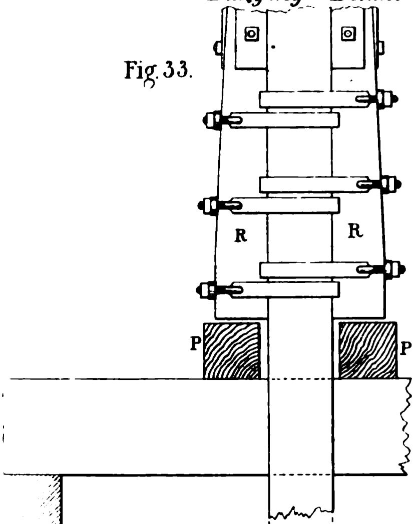
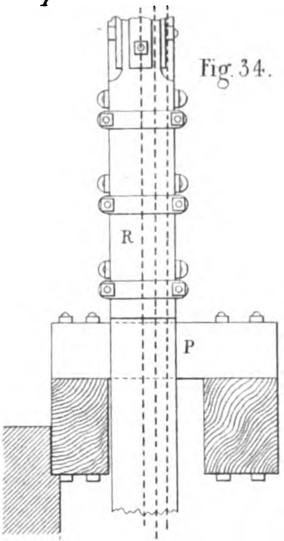


Fig. 34.



Top Spear Guide.

Fig. 35.

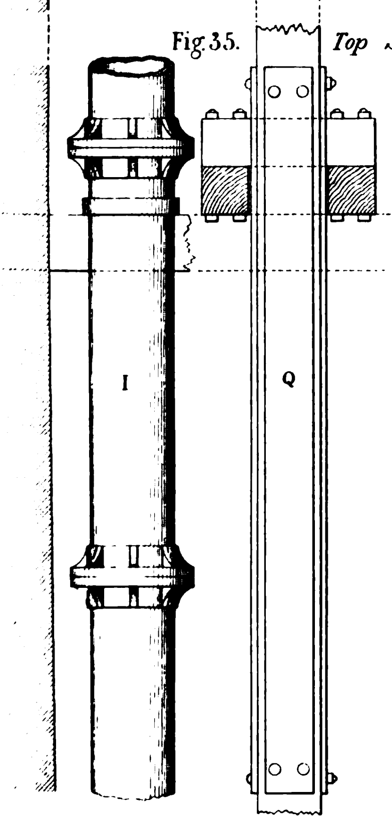
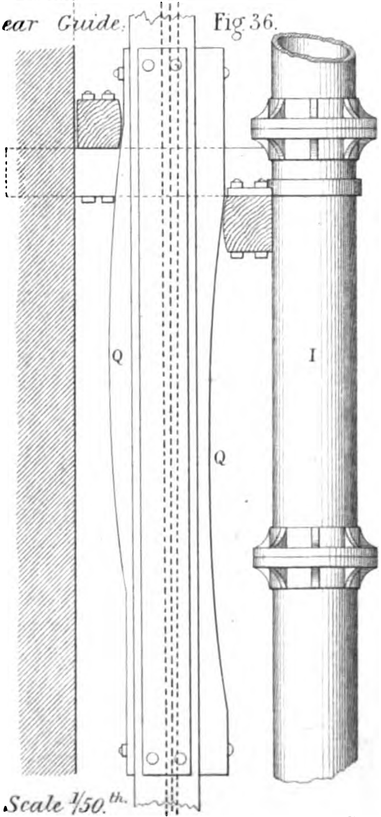


Fig. 36.



(Proceedings Inst. M.E. 1863. Page 248.)

Scale 1/50th.

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 Feet

CLAY CROSS PUMPING ENGINE. *Plate 79.*

Indicator Diagrams.

Steam Pressure in Boilers 14 lbs. per square inch above atmosphere.

Fig. 37. *Steam cut off at 71 per cent. of stroke.*

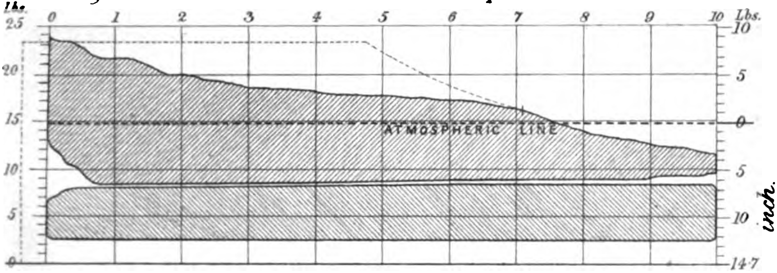


Fig. 38. *Steam cut off at 82 per cent. of stroke.*

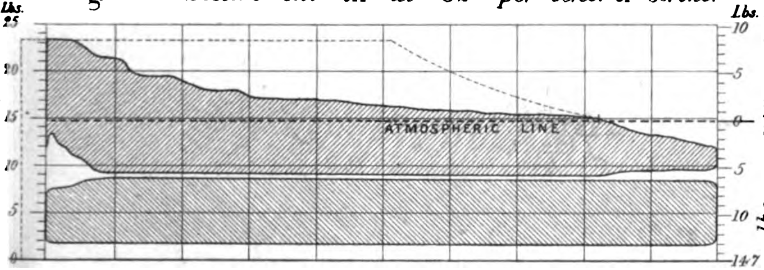


Fig. 39. *Steam cut off at 84 per cent. of stroke.*

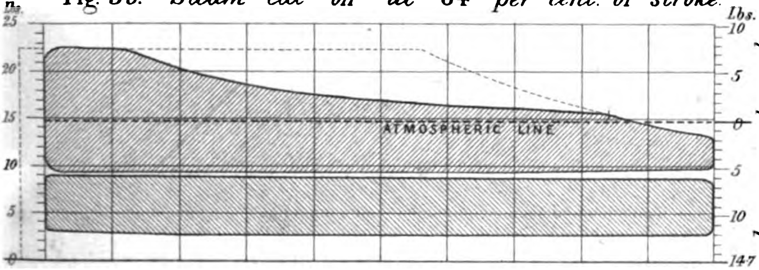
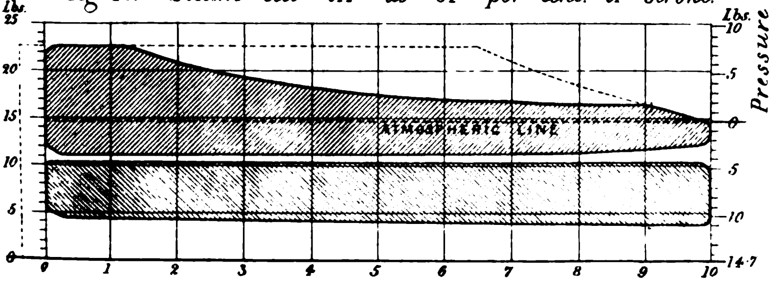


Fig. 40. *Steam cut off at 91 per cent. of stroke.*



(Proceedings Inst. M. E. 1863. Page 248.)

POLISHED SHEET GLASS.

Plate 80.

Melting Furnace.

Fig. 1. *Transverse Section.*

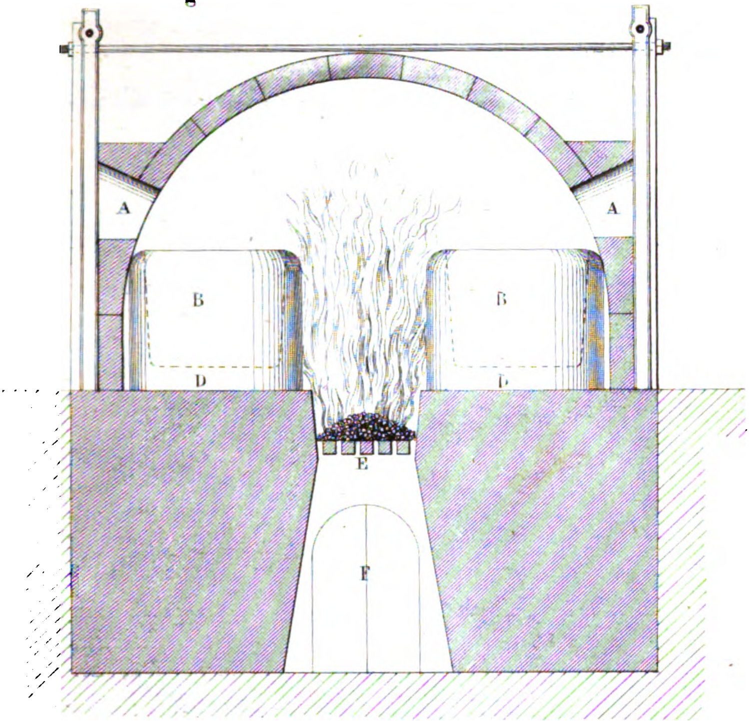
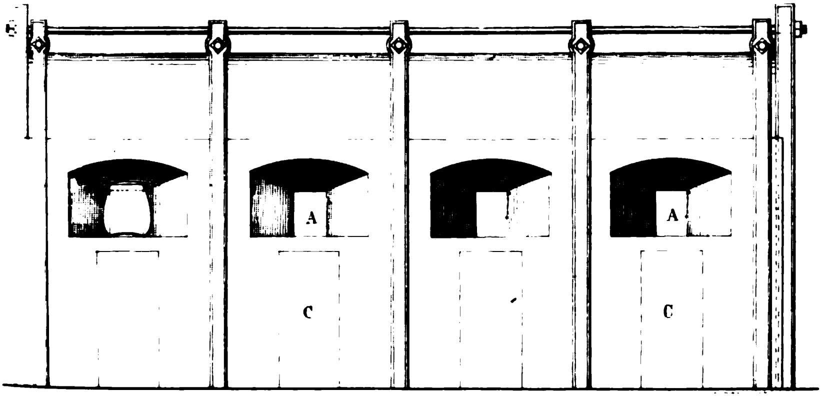


Fig. 2. *Side Elevation.*



(Proceedings Inst. M.E. 1863. Page 268.) *Scale 1/80 th.*

0 10 20 Feet.

Fig. 3. *Blow-Pipe.*

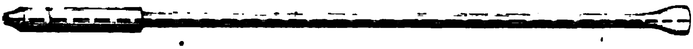


Fig. 4. *Solid Gathering.*

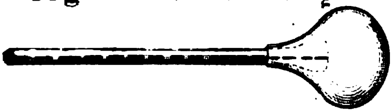


Fig. 5. *Drawing Out.*

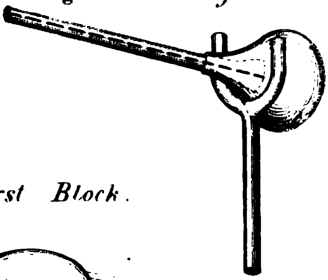


Fig. 6. *First Block.*

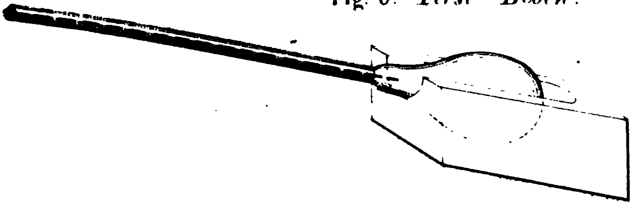


Fig. 7. *Second Block.*

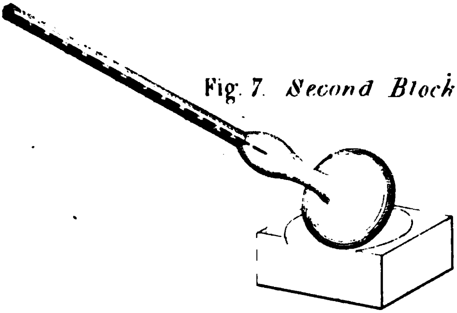
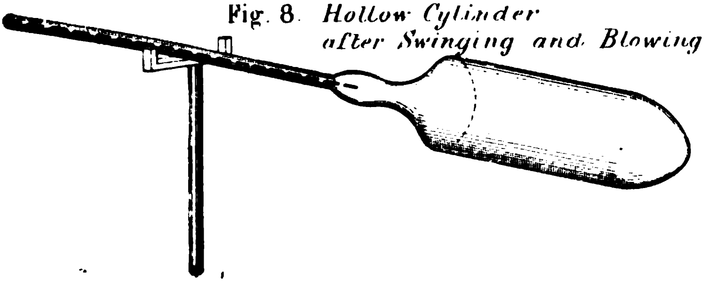


Fig. 8. *Hollow Cylinder after Swinging and Blowing.*



(Proceedings Inst. M. E. 1863. Page 268.) *Scale 1/20th.*

Fig. 9. *Flashing Outer end of Cylinder.*

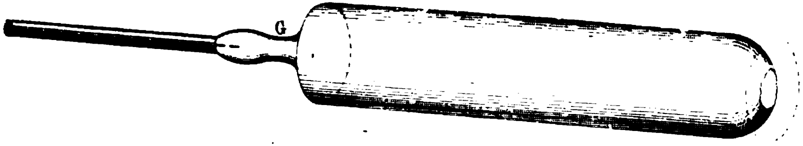


Fig. 10. *Breaking off Blow-pipe end of Cylinder.*

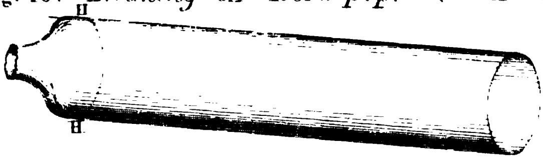
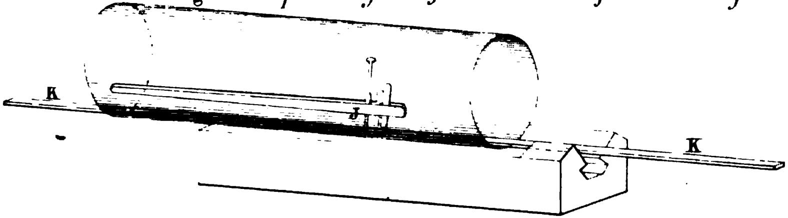


Fig. 12. *Splitting Cylinder longitudinally.*



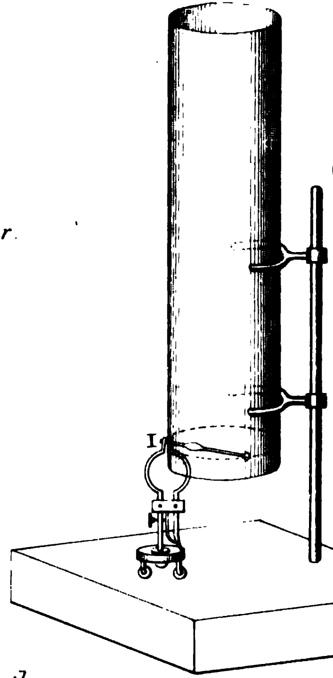
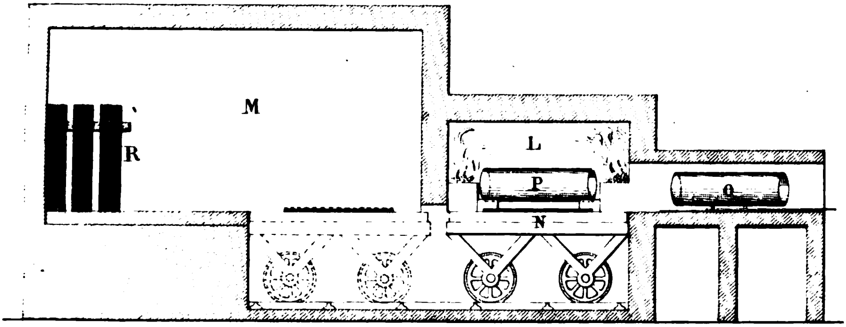


Fig. 11.
Cutting off Flashed end of Cylinder.

(Proceedings Inst. M. E. 1863. Page 268.)

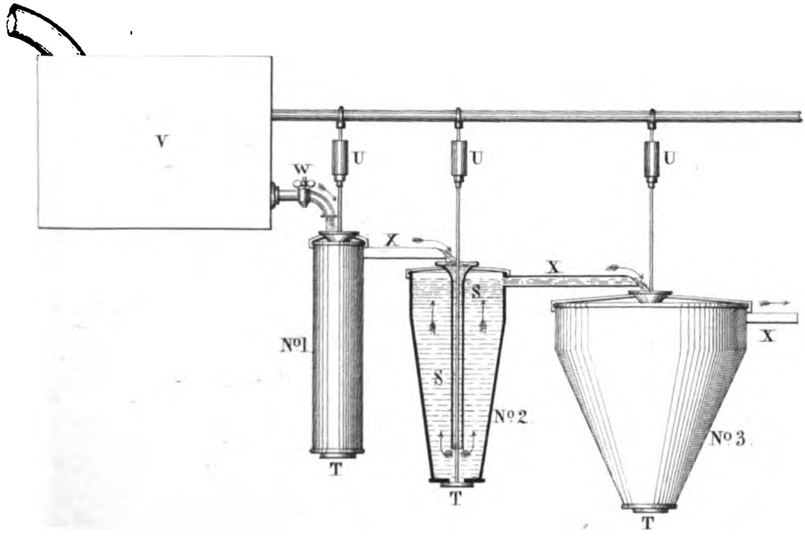
Scale 1/20th

Fig. 13. *Flattening and Annealing Kiln.*



Scale 1/80th 0 5 10 15 20 *Feet.*

Fig. 14. *Emery Sorting Apparatus.*



Scale 1/20th

10 5 0 10 20 30 40 50 *Inches.*

(Proceedings Inst. M.E. 1863. Page 268.)

INSTITUTION

OF

MECHANICAL ENGINEERS.

PROCEEDINGS.

1864.

PUBLISHED BY THE INSTITUTION,
81 NEWHALL STREET, BIRMINGHAM.

BIRMINGHAM:
PRINTED AT MARTIN BILLING, SON, AND CO.'S STEAM-PRESS OFFICES,
LIVERY STREET.

INDEX.

1864.

PAGE
Annual Report . . . 1
Blast Furnaces, Construction of, in Cleveland district, by J. G. Beckton 249
Blast Furnaces, Working and Capacity of, by C. Cochrane . . . 163
Boiler, Cast Iron Steam, Harrison's, by Z. Colburn . . . 61
Coal Cutting Machine, by T. Levick . . . 272
Coalfield, Glasgow, principal Seams of Coal and Ironstone in, by W. Moore 229
Cranes, Traversing, at Crewe Locomotive Works, by J. Ramsbottom . . . 44
Dredgers, Steam, on the Clyde, by A. Duncan . . . 147
Locomotives, Distribution of Weight on Axles of, by J. Robinson . . . 92
Memoirs of Members deceased in 1863 . . . 13
Puddling Iron by Machinery, by H. Bennett . . . 298
Pump, Horizontal V, by J. J. Birckel . . . 33
Stone Breaking Machine, for Breaking Limestone and Ore, by J. Lancaster 20
Subjects for Papers . . . 5
Tools, Heavy, for general Engineering and Iron Shipbuilding Work, by J. Fletcher . . . 189
Water Works, Loch Katrine, for supply of Glasgow, Mechanical Appliances of, by J. M. Gale . . . 123

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81 *Newhall Street, Birmingham.*

LIST OF MEMBERS,

WITH YEAR OF ELECTION.

1864.

LIFE MEMBERS.

1858. Bower, John Wilkes, Lancashire and Yorkshire Railway, Engineer's Office, Manchester.
1852. Brogden, Henry, Sale, near Manchester.
1858. Fletcher, Henry Allason, Lowca Engine Works, Whitehaven.
1857. Haughton, S. Wilfred, 62 Lower Baggot Street, Dublin.
1854. Lloyd, George Braithwaite, Messrs. Lloyds, High Street, Birmingham.
1853. Maudslay, Henry, Cheltenham Place, Lambeth, London, S.
1856. Napier, Robert, West Shandon, Helensburgh, near Glasgow.
1848. Penn, John, The Cedars, Lee, Kent, S.E.
1864. Tennant, Charles, The Glen, Innerleithen, near Edinburgh.
1863. Wicksteed, Thomas, 8 Torquay Terrace, Headingley, near Leeds.

MEMBERS.

1861. Abel, Charles Denton, 20 Southampton Buildings, London, W.C.
1848. Adams, William Alexander, Midland Works, Birmingham.
1859. Adamson, Daniel, Newton Moor Iron Works, Hyde, near Manchester.
1861. Addenbrooke, George, Rough Hay Furnaces, Darlaston, near Wednesbury.
1851. Addison, John, 6 Delahay Street, Westminster, S.W.
1858. Albaret, Auguste, Engine Works, Liancourt, Oise, France.
1847. Allan, Alexander, Locomotive Superintendent, Scottish Central Railway, Perth.
1856. Allen, James, Cambridge Street Works, Manchester.
1859. Alton, George, Midland Railway Works, Derby.
1861. Amos, Charles Edwards, Grove Works, Southwark, London, S.E.
1856. Anderson, John, Assistant Superintendent, Royal Gun Factories, and Inspector of Machinery to the War Department, Royal Arsenal, Woolwich, S.E.
1856. Anderson, William, Erith Iron Works, Erith, Kent, S.E.
1862. Angus, Robert, Locomotive Superintendent, North Staffordshire Railway, Stoke-upon-Trent.

1858. Appleby, Charles Edward, Renishaw Iron Works, near Chesterfield.
1859. Armitage, William James, Farnley Iron Works, Leeds.
1863. Armstrong, John, Timber Works, 20 North Bridge Street, Sunderland.
1857. Armstrong, Joseph, Locomotive Superintendent, Great Western Railway, Swindon.
1858. Armstrong, Sir William George, Elswick, Newcastle-on-Tyne.
1857. Ashbury, James Lloyd, Openshaw Works, near Manchester.
1848. Ashbury, John, Openshaw Works, near Manchester.
1858. Atkinson, Charles, Fitzalan Steel Works, Sheffield.

1860. Bailey, Samuel, Mining Engineer, The Pleck, near Walsall.
1860. Barclay, John, Bowling Iron Works, near Bradford, Yorkshire.
1860. Barker, Paul, Old Park Iron Works, Wednesbury.
1863. Barlow, Edward, Messrs. Dobson and Barlow, Machine Works, Bolton.
1862. Barrow, Joseph, 93 Argyle Terrace, Bristol Street, Hulme, Manchester.
1862. Barton, Edward, 1 Market Street, Manchester.
1847. Barwell, William Harrison, Eagle Foundry, Northampton.
1859. Bastow, Samuel, Cliff House Iron Works, West Hartlepool.
1860. Batho, William Fothergill, Messrs. Nettlefold and Chamberlain, Smethwick Screw Works, Birmingham.
1859. Beacock, Robert, Victoria Foundry, Leeds.
1860. Beale, William Phipson, 27 Victoria Street, Westminster, S.W.
1848. Beattie, Joseph, Locomotive Superintendent, London and South Western Railway, Nine Elms, London, S.
1859. Beck, Edward, Messrs. Neild and Co., Dallam Iron Works, Warrington.
1862. Beckett, Henry, Mining Engineer, Upper Penn, Wolverhampton.
1864. Beckton, James George, Whitby.
1858. Bell, Isaac Lowthian, Clarence Felling and Wylam Iron Works, Newcastle-on-Tyne.
1857. Bellhouse, Edward Taylor, Eagle Foundry, Hunt Street, Oxford Street, Manchester.
1854. Bennett, Peter Duckworth, Spon Lane Iron Foundry, Westbromwich.
1861. Bessemer, Henry, 4 Queen Street Place, New Cannon Street, London, E.C.
1847. Beyer, Charles F., Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.
1861. Binns, Charles, Mining Engineer, Clay Cross, near Chesterfield.
1863. Birckel, John James, Vauxhall Foundry, Liverpool.
1847. Birley, Henry, Haigh Foundry, near Wigan.
1856. Blackburn, Isaac, Witton Park Iron Works, Darlington.
1851. Blackwell, Samuel Holden, Dudley.
1862. Blake, Henry Wollaston, Messrs. James Watt and Co., 18 London Street, London, E.C.

1862. Blyth, Alfred, Steam Engine Works, Fore Street, Limehouse, London, E.
1863. Boeddinghaus, Julius, Messrs. Heinrich Boeddinghaus and Sons, Elberfeld, Prussia.
1862. Bouch, Thomas, 78 George Street, Edinburgh.
1858. Bouch, William, Shildon Engine Works, Darlington.
1847. Bovill, George Hinton, 24 Duke Street, Westminster, S.W.
1862. Boyd, Nelson, Belfast Foundry, Donegal Street, Belfast.
1854. Bragge, William, Atlas Steel and Iron Works, Sheffield.
1854. Bramwell, Frederick Joseph, 35A Great George Street, Westminster, S.W.
1856. Bray, Edwin, Nevill Holt, near Market Harborough.
1861. Brierly, Henry, 27 Southampton Buildings, London, W.C.
1848. Broad, Robert, Horseley Iron Works, near Tipton.
1863. Brown, Henry, Metropolitan Carriage and Wagon Company, Saltley Works, Birmingham.
1847. Brown, James, Jun., Messrs. James Watt and Co., Soho Foundry, near Birmingham.
1850. Brown, John, Atlas Steel and Iron Works, Sheffield.
1855. Brown, John, Mining Engineer, Barnsley.
1853. Brown, Ralph, Patent Shaft Works, Wednesbury.
1863. Brown, William Steel, Edinburgh and Glasgow Railway, Cowlairs, Glasgow.
1858. Burn, Henry, Midland Railway, Locomotive Department, Derby.
1856. Butler, Ambrose Edmund, Kirkstall Forge, Leeds.
1863. Butler, Arthur, Surdah, Radshye, Lower Bengal, India: (or care of Walter Butler, 1 Westminster Chambers, Victoria Street, Westminster, S.W.)
1859. Butler, John, Old Foundry, Stanningley, near Leeds.
1859. Butler, John Octavius, Kirkstall Forge, Leeds.

1857. Cabry, Joseph, 3 Colbeck Terrace, Tynemouth, near North Shields.
1847. Cabry, Thomas, North Eastern Railway, York.
1847. Cammell, Charles, Cyclops Steel and Iron Works, Sheffield.
1864. Campbell, David, 20 Castle Street, Liverpool.
1860. Cannell, Fleetwood James, Old Park Iron Works, Wednesbury.
1860. Carbutt, Edward Hamer, Vulcan Iron Works, Thornton Road, Bradford, Yorkshire.
1862. Carpmael, William, 24 Southampton Buildings, London, W.C.
1856. Carrett, William Elliott, Sun Foundry, Leeds.
1864. Carrington, William Thomas, 18 Great George Street, Westminster, S.W.
1858. Carson, James Irving, Locomotive Superintendent, West Hartlepool Harbour and Railway, Stockton-on-Tees.
1849. Chamberlain, Humphrey, 3 St. John's, Wakefield.
1857. Chrimes, Richard, Brass Works, Rotherham.
1854. Clark, Daniel Kinnear, 11 Adam Street, Adelphi, London, W.C.

1859. Clark, George, Monkwearmouth Engine Works, Sunderland.
1862. Clark, James, 4 Corporation Street, Manchester.
1859. Clay, William, Mersey Steel and Iron Works, Sefton Street, Liverpool.
1863. Clayton, Robert, Soho Foundry, Preston.
1847. Clift, John Edward, Durnford Place, Coventry Road, Birmingham.
1860. Clunes, Thomas, Worcester Engine Works, Worcester.
1858. Cochrane, Charles, Woodside Iron Works, near Dudley.
1860. Cochrane, Henry, Ormesby Iron Works, Middlesbrough.
1854. Cochrane, John, Woodside Iron Works, near Dudley.
1864. Coddington, William, Ordnance Cotton Mill, Blackburn.
1847. Coke, Richard George, Mining Engineer, Chesterfield.
1864. Colburn, Zerah, 7 Gloucester Road, Regent's Park, London, N.W.
1853. Cooper, Samuel Thomas, Leeds Iron Works, Leeds.
1860. Cope, James, Mining Engineer, Pensnett, near Dudley.
1848. Corry, Edward, 8 New Broad Street, London, E.C.
1857. Cortazzi, Francis James, Locomotive Superintendent, Great Indian Peninsula Railway, Bombay, India: (or care of Thomas Dyson Hornby, 8 Brunswick Street, Liverpool.)
1860. Coulthard, Hiram Craven, Park Iron Works, Blackburn.
1864. Cowans, John, St. Nicholas and Woodbank Iron Works, Carlisle.
1847. Cowper, Edward Alfred, 35A Great George Street, Westminster, S.W.
1862. Cox, Samuel H. F., 3 East Parade, Sheffield.
1863. Craig, Andrew, Rock Ferry, Birkenhead.
1847. Crampton, Thomas Russell, 12 Great George Street, Westminster, S.W.
1858. Crawhall, Joseph, St. Ann's Wire and Hemp Rope Works, Newcastle-on-Tyne.
1857. Criswick, Theophilus, Lydbrook Deep Level Collieries, near Ross.
1863. Crow, George, Messrs. R. Stephenson and Co., South Street, Newcastle-on-Tyne.
1864. Crowe, Edward, Tees Side Iron Works, Middlesbrough.
1858. Cubitt, Charles, 3 Great George Street, Westminster, S.W.

1864. Daglish, George Heaton, St. Helen's Foundry, St. Helen's.
1864. Darby, Charles E., Brymbo Iron Works, near Wrexham.
1863. Davy, Alfred, Park Iron Works, Sheffield.
1849. Dawes, George, Milton and Elsecar Iron Works, near Barnsley.
1860. Dawes, William Henry, Bromford Iron Works, Westbromwich.
1861. Dawson, Benjamin, South Hetton, near Fence Houses.
1862. Deakin, William, Monmer Lane Iron Works, Willenhall, near Wolverhampton.
1857. De Bergue, Charles, Strangeways Iron Works, Manchester.
1858. Dees, James, Whitehaven.

1858. Dempsey, William, 26 Great George Street, Westminster, S.W.
1864. Dewhurst, John, Wadsley Bridge Iron and Steel Works, near Sheffield.
1859. Dixon, John, Railway Foundry, Bradford, Yorkshire.
1861. Dixon, Thomas, Low Moor Iron Works, near Bradford, Yorkshire.
1857. Douglas, George K., Messrs. R. Stephenson and Co., South Street, Newcastle-on-Tyne.
1857. Dove, George, St. Nicholas and Woodbank Iron Works, Carlisle.
1847. Dubs, Henry, Glasgow Locomotive Works, Glasgow.
1857. Dunlop, John Macmillan, Marlborough Street, Oxford Street, Manchester.
1854. Dunn, Thomas, Windsor Bridge Iron Works, Manchester.
1864. Dunn, Thomas Edward, Jumna Bridge, East Indian Railway, Allahabad, India: (or care of R. Dunn, Howick, near Alnwick).
1861. Dutton, Charles, Bromford Iron Works, Westbromwich.
1860. Dyson, George, Tudhoe Iron Works, near Ferryhill.

1859. Eassie, Peter Boyd, Saw Mills, High Orchard, Gloucester.
1858. Easton, Edward, Grove Works, Southwark, London, S.E.
1856. Eastwood, James, Railway Iron Works, Derby.
1862. Elder, John, Messrs. Randolph Elder and Co., Centre Street, Glasgow.
1859. Elliot, George, Houghton-le-Spring, near Fence Houses.
1860. Elwell, Thomas, Messrs. Varrall Elwell and Poulot, 9 Avenue Trudaine, Paris.
1853. England, George, Hatcham Iron Works, London, S.E.
1861. Esson, William, Engineer, Cheltenham Gas Works, Cheltenham.
1864. Etienne, Antonin, Engineer, Cordova and Seville Railway, Seville, Spain.
1857. Evans, John Campbell, Morden Iron Works, East Greenwich, S.E.
1848. Everitt, George Allen, Kingston Metal Works, Adderley Street, Birmingham.
1864. Everitt, William Edward, Kingston Metal Works, Adderley Street, Birmingham.

1857. Fairlie, Robert Francis, 56 Gracechurch Street, London, E.C.
1861. Fearnley, Thomas, Globe Works, Hall Lane, Bradford, Yorkshire.
1854. Fernie, John, Clarence Iron Works, Leeds.
1861. Field, Joshua, Cheltenham Place, Lambeth, London, S.
1864. Fleet, Thomas, Crown Boiler Works, Westbromwich.
1861. Fleetwood, Daniel Joseph, Metal Rolling Mills, Icknield Port Road, Birmingham.
1847. Fletcher, Edward, Locomotive Superintendent, North Eastern Railway, Gateshead.
1857. Fletcher, James, Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.

1859. Fogg, Robert, 17 Park Street, Westminster, S.W.
1861. Forster, Edward, Spon Lane Glass Works, near Birmingham.
1849. Forsyth, John C., North Staffordshire Railway, Stoke-upon-Trent.
1864. Foster, Edward Henry, Old Park Iron Works, Wednesbury.
1861. Foster, Sampson Lloyd, Old Park Iron Works, Wednesbury.
1847. Fothergill, Benjamin, 27 Cornhill, London, E.C.
1847. Fowler, John, 2 Queen Square Place, Westminster, S.W.
1857. Fowler, John, Steam Plough Works, Leeds.
1847. Fox, Sir Charles, 8 New Street, Spring Gardens, London, S.W.
1864. Frankish, John, 1 Lord's Chambers, Corporation Street, Manchester.
1859. Fraser, John, 18 York Place, Leeds.
1853. Fraser, Joseph Boyes, Alma Place, Kenilworth.
1856. Freeman, Joseph, 22 Cannon Street, London, E.C.
1864. Frost, Thomas, Canal Street Iron Works, Derby.
1852. Froude, William, Elmsleigh, Paignton, Torquay.

1862. Galton, Capt. Douglas, R.E., War Office, Pall Mall, London, S.W.
1847. Garland, William S., Messrs. James Watt and Co., Soho Foundry, near Birmingham.
1848. Gibbons, Benjamin, Hill Hampton House, near Stourport.
1856. Gilkes, Edgar, Tees Engine Works, Middlesbrough.
1862. Godfrey, Samuel, Messrs. Bolckow and Vaughan's Iron Works, Middlesbrough.
1848. Green, Charles, Tube Works, Leek Street, Birmingham.
1861. Green, Edward, Jun., 3 Bank Street, Exchange, Manchester.
1858. Greenwood, Thomas, Albion Works, Armley Road, Leeds.
1857. Gregory, John, Engineer, Portuguese National Railway South of Tagus, Barriero, near Lisbon, Portugal.
1860. Grice, Frederic Groom, Stour Valley Works, Spon Lane, Westbromwich.

1861. Haden, William, Dixon's Green, Dudley.
1861. Haggie, Peter, Hemp and Wire Rope Works, Gateshead.
1864. Halkett, John Craigie, Cramond Iron Works, Edinburgh.
1863. Hall, Joseph, Gratz Iron Works, Gratz, Styria, Austria.
1857. Hall, William, Ashted Varnish and Colour Works, 167 Dartmouth Street, Birmingham.
1860. Hamilton, Gilbert, Messrs. James Watt and Co., Soho Foundry, Birmingham.
1858. Harding, John, Beeston Manor Iron Works, Leeds.
1859. Harman, Henry William, Canal Street Works, Manchester.
1856. Harrison, George, Canada Works, Birkenhead.
1858. Harrison, Thomas Elliot, 1 Westminster Chambers, Victoria Street, Westminster, S.W.

1863. Hartas, Isaac, Rosedale Iron Mines, near Pickering, Yorkshire.

1858. Haswell, John A., North Eastern Railway, Locomotive Department, Gateshead.

1861. Hawkins, William Bailey, 24 Budge Row, Cannon Street, London, E.C.

1856. Hawksley, Thomas, 30 Great George Street, Westminster, S.W.

1848. Hawthorn, Robert, Forth Banks, Newcastle-on-Tyne.

1848. Hawthorn, William, Forth Banks, Newcastle-on-Tyne.

1862. Haynes, Thomas John, Calp Foundry, North Front, Gibraltar.

1860. Head, John, Messrs. Ransomes and Sims, Orwell Works, Ipswich.

1858. Head, Thomas Howard, Teesdale Iron Works, Stockton-on-Tees.

1853. Headly, James Ind, Eagle Works, Cambridge.

1857. Healey, Edward Charles, 163 Strand, London, W.C.

1862. Heath, William J. W., Assistant Engineer, Ceylon Railway, Colombo, Ceylon; (or care of John J. Heath, 105 Vyse Street, Birmingham.)

1864. Heathfield, Richard, Lion Galvanising Works, Birmingham Heath, Birmingham.

1860. Heaton, George, Royal Copper Mint, Icknield Street East, Birmingham.

1858. Hedley, John, 4 High Swinburn Place, Newcastle-on-Tyne.

1864. Hetherington, William Isaac, Vulcan Works, Pollard Street, Manchester.

1864. Hide, Thomas C., 46 Fenchurch Street, London, E.C.

1863. Hind, Roger, Scotland Bank Iron Works, Warrington.

1862. Hingley, Samuel, Hart's Hill Iron Works, near Brierley Hill.

1858. Hodgson, Robert, North Eastern Railway, Newcastle-on-Tyne.

1852. Holcroft, James, Shut End, Brierley Hill.

1863. Holt, Frank, Gorton Foundry, Manchester.

1848. Homersham, Samuel Collett, 19 Buckingham Street, Adelphi, London, W.C.

1860. Hopkins, James Innes, Tees Side Iron Works, Middlesbrough.

1856. Hopkinson, John, London Road Iron Works, Manchester.

1858. Hopper, George, Houghton-le-Spring Iron Works, near Fence Houses.

1858. Horsley, William, Jun., Whitehill Point Iron Works, Percy Main, near Newcastle-on-Tyne.

1851. Horton, Joshua, Ætna Works, Smethwick, near Birmingham.

1858. Hosking, John, Gateshead Iron Works, Gateshead.

1864. Howard, Eliot, 84 Upper Whitecross Street, London, E.C.

1860. Howard, James, Britannia Iron Works, Bedford.

1860. Howe, William, Clay Cross Coal and Iron Works, near Chesterfield.

1861. Howell, Joseph Bennett, Hartford Steel Works, Sheffield.

1862. Huber, Peter Emile, Vogelhutte, Zurich, Switzerland.

1864. Hulse, William Wilson, The Grove, Withington, Manchester.

1847. Humphrys, Edward, Deptford Pier, London, S.E.

1859. Hunt, James P., Corngreaves Iron Works, Corngreaves, near Birmingham.

1856. Hunt, Thomas, Tudela and Bilbao Railway, Bilbao, Spain; (or 3 Stanley Place, Preston.)

1864. Hutchinson, Edward, Skerne Iron Works, Darlington.
1863. Hutton, Walter Stuart, Prospect Works, Hunslet Lane, Leeds.

1857. Inshaw, John, Engine Works, Morville Street, Birmingham.

1859. Jackson, Matthew Murray, Messrs. Escher Wyss and Co., Engine Works, Zurich, Switzerland.
1847. Jackson, Peter Rothwell, Salford Rolling Mills, Manchester.
1861. Jackson, Robert, Ætna Steel Works, Sheffield.
1860. Jackson, Samuel, Cyclops Steel and Iron Works, Sheffield.
1858. Jaffrey, George William, Hartlepool Iron Works, Hartlepool.
1856. James, Jabez, 28A Broadwall, Stamford Street, Lambeth, London, S.
1855. Jeffcock, Parkin, Mining Engineer, Midland Road, Derby.
1861. Jeffcock, Thomas William, Mining Engineer, 18 Bank Street, Sheffield.
1863. Jeffreys, Edward A., Low Moor Iron Works, near Bradford, Yorkshire.
1857. Jenkins, William, Locomotive Superintendent, Lancashire and Yorkshire Railway, Miles Platting, Manchester.
1861. Jessop, Sydney, Park Steel Works, Sheffield.
1861. Jessop, Thomas, Park Steel Works, Sheffield.
1854. Jobson, John, Derwent Foundry, Derby.
1863. Johnson, Bryan, Flookersbrook Foundry, Chester.
1847. Johnson, James, North Staffordshire Railway, Engineer's Office, Stoke-upon-Trent.
1861. Johnson, Samuel Waite, Locomotive Superintendent, Edinburgh and Glasgow Railway, Cowlairs, Glasgow.
1861. Jones, Alfred, Ettingshall Iron Works, Bilston.
1861. Jones, David, Engineer, Rumney Railway, Machen, near Newport, Monmouthshire.
1847. Jones, Edward, Old Park Iron Works, Wednesbury.
1857. Jones, John Hodgson, 26 Great George Street, Westminster, S.W.
1853. Joy, David, Cleveland Engine Works, Middlesbrough.

1857. Kay, James Clarkson, Phœnix Foundry, Bury, Lancashire.
1857. Kendall, William, Locomotive Superintendent, Blyth and Tyne Railway, Percy Main, near Newcastle-on-Tyne.
1863. Kennan, James, Agricultural Implement Works, 19 Fishamble Street, Dublin.
1847. Kennedy, James, Cressington Park, Aigburth, Liverpool.
1857. Kennedy, Lt.-Colonel John Pitt, Engineer, Bombay Baroda and Central Indian Railway; 10 Liverpool Street, New Broad Street, London, E.C.
1863. Kennedy, John Pitt, Bombay Baroda and Central Indian Railway; 10 Liverpool Street, New Broad Street, London, E.C.

1848. Kirkham, John, 109 Euston Road, London, N.W.
1847. Kirtley, Matthew, Locomotive Superintendent, Midland Railway, Derby.
1864. Kirtley, William, Midland Railway, Locomotive Department, Derby.
1859. Kitson, Frederick William, Monkbridge Iron Works, Leeds.
1848. Kitson, James, Airedale Foundry, Leeds.
1859. Kitson, James, Jun., Monkbridge Iron Works, Leeds.
1863. Knight, Thomas, 130 Bradford Street, Birmingham.
1862. Knott, Joseph, Pennington Cotton Mill, Leigh, near Manchester.

1863. Lancaster, John, Kirkless Hall Coal and Iron Works, near Wigan.
1863. Latham, Ernest, 28 Clarence Square, Gosport.
1860. Law, David, Phœnix Iron Works, Glasgow.
1857. Laybourn, John, Isca Foundry, Newport, Monmouthshire.
1856. Laybourn, Richard, Locomotive Superintendent, Monmouthshire Railway and Canal Company, Newport, Monmouthshire.
1860. Lea, Henry, 33 Waterloo Street, Birmingham.
1862. Lee, J. C. Frank, 30 Parliament Street, Westminster, S.W.
1860. Lee, John, Midland Railway, Locomotive Department, Derby.
1863. Lees, Samuel, Jun., Park Bridge Iron Works, Ashton-under-Lyne.
1863. Leigh, Evan, Miles Platting, Manchester.
1858. Leslie, Andrew, Iron Ship Building Yard, Hebburn Quay, Gateshead.
1856. Levick, Frederick, Cwm-Celyn Blaina and Coalbrook Vale Iron Works, near Newport, Monmouthshire.
1860. Lewis, Thomas William, Plymouth Iron Works, Merthyr Tydvil.
1864. Lindsley, George, Great Western Railway, Locomotive Department, Paddington, London, W.
1856. Linn, Alexander Grainger, 2 Queen Square Place, Westminster, S.W.
1857. Little, Charles, Staveley Coal and Iron Works, Staveley, near Chesterfield.
1863. Lloyd, Edward R., Albion Tube Works, Nile Street, Birmingham.
1862. Lloyd, John, Lilleshall Iron Works, Oakengates, near Wellington, Shropshire.
1847. Lloyd, Sampson, Old Park Iron Works, Wednesbury.
1864. Lloyd, Sampson Zachary, Old Park Iron Works, Wednesbury.
1852. Lloyd, Samuel, Old Park Iron Works, Wednesbury.
1862. Lloyd, Wilson, Old Park Iron Works, Wednesbury.
1863. Loam, Matthew Hill, Engineer, Gas and Water Works, Nottingham.
1856. Longridge, Robert Bewick, Steam Boiler Assurance Company, 67 King Street, Manchester.
1859. Lord, Thomas Wilks, 2A Alfred Street, Boar Lane, Leeds.
1861. Low, George, Millgate Iron Works, Newark.
1854. Lynde, James Gascoigne, Town Hall, Manchester.

1864. Macfarlane, Walter, Saracen Foundry, Glasgow.

1856. Mackay, John, Mount Hermon, Drogheda.

1864. Macnab, Archibald Francis, Fazeley Street Wire Mills, Birmingham.

1859. Manning, John, Boyne Engine Works, Hunslet, Leeds.

1862. Mansell, Richard Christopher, South Eastern Railway, Carriage Department, Ashford.

1862. Mappin, Frederick Thorpe, Sheaf Works, Sheffield.

1857. March, George, Union Foundry, Leeds.

1856. Markham, Charles, Staveley Coal and Iron Works, Staveley, near Chesterfield.

1848. Marshall, Edwin, Britannia Carriage Works, Birmingham.

1862. Marshall, James, Bunker Hill, Fence Houses.

1859. Marshall, William Ebenezer, Sun Foundry, Leeds.

1847. Marshall, William Prime, 81 Newhall Street, Birmingham.

1859. Marten, Edward Bindon, Engineer, Stourbridge Water Works, 13 High Street, Stourbridge.

1853. Marten, Henry, Parkfield Iron Works, near Wolverhampton.

1857. Martindale, Capt. Ben Hay, R.E., War Office, Pall Mall, London, S.W.

1854. Martineau, Francis Edgar, Globe Works, Cliveland Street, Birmingham.

1864. Martley, William, Locomotive Superintendent, London Chatham and Dover Railway, Longhedge Works, Wandsworth Road, London, S.

1857. Masselin, Armand, 16 Rue Dauphine, Paris.

1853. Mathews, William, Corbyn's Hall Iron Works, near Dudley.

1848. Matthew, John, Messrs. John Penn and Co., Marine Engineers, Greenwich, S.E.

1847. Matthews, William Anthony, Sheaf Works, Sheffield.

1864. Maudslay, Thomas Henry, Cheltenham Place, Lambeth, London, S.

1861. May, Robert Charles, 3 Great George Street, Westminster, S.W.

1857. May, Walter, Suffolk Works, Berkley Street, Birmingham.

1859. Maylor, William, East Indian Iron Company, Beypoor, India: (or care of E. J. Burgess, Abchurch Chambers, Abchurch Yard, London, E.C.)

1847. McClean, John Robinson, 23 Great George Street, Westminster, S.W.

1864. McEwen, Lawrence Thomson, Ormesby Iron Works, Middlesbrough.

1860. McKenzie, James, Well House Foundry, Leeds.

1859. McKenzie, John, Worcester Engine Works, Worcester.

1862. McPherson, Hugh, Engineer, Gloucester Gas Works, Gloucester.

1863. Meek, Sturges, Resident Engineer, Lancashire and Yorkshire Railway, Manchester.

1858. Meik, Thomas, Engineer to the River Wear Commissioners, Sunderland.

1857. Menelaus, William, Dowlais Iron Works, Merthyr Tydvil.

1857. Metford, William Ellis, Flook House, Taunton.

1847. Middleton, William, Vulcan Iron Foundry, Summer Lane, Birmingham.

1862. Miers, Francis C., Stoneleigh Lodge, Grove Road, Clapham Park, London, S.
1864. Miers, John William, 74 Addison Road, Kensington, London, W.
1853. Miller, George Mackay, Great Southern and Western Railway, Dublin.
1862. Millward, John, Union Chambers, High Street, Stourbridge.
1856. Mitchell, Charles, Iron Ship Building Yard, Low Walker, Newcastle-on-Tyne.
1858. Mitchell, James, 3 Church Terrace, Higher Tranmere, Birkenhead.
1861. Mitchell, Joseph, Worsbrough Dale Colliery, near Barnsley.
1859. Moor, William, Engineer, Hetton Colliery, Hetton, near Fence Houses.
1864. Moore, Sampson, North Foundry, Williams Street, Clarence Dock, Liverpool.
1864. Morgan, Joshua Llewelyn, Woodside, Cwmbran, near Newport, Monmouthshire.
1849. Morrison, Robert, Ouseburn Engine Works, Newcastle-on-Tyne.
1858. Mountain, Charles George, Suffolk Works, Berkley Street, Birmingham.
1863. Muir, William, Britannia Works, Manchester.
1857. Muntz, George Frederick, French Walls, near Birmingham.
1859. Murphy, James, Railway Works, Newport, Monmouthshire.
1858. Murray, Thomas H., Engine Works, Chester-le-Street, near Fence Houses.
1863. Musgrave, John, Jun., Globe Iron Works, Bolton.

1848. Napier, John, Vulcan Foundry, Glasgow.
1861. Naylor, John William, Wellington Foundry, Leeds.
1858. Naylor, William, Great Indian Peninsula Railway, 3 New Broad Street, London, E.C.
1863. Neilson, Walter Montgomerie, Hyde Park Locomotive Works, Glasgow.
1860. Nettlefold, Joseph Henry, Screw Works, Broad Street, Birmingham.
1856. Newall, James, East Lancashire Railway, Carriage Department, Bury, Lancashire.
1862. Newton, William Edward, 66 Chancery Lane, London, W.C.
1858. Nichol, Peter Dale, Locomotive Superintendent, East Indian Railway, Allahabad, India: (or care of Anthony Nichol, 22 Quay, Newcastle-on-Tyne.)
1850. Norris, Richard Stuart, 272 Upper Parliament Street, Liverpool.

1864. Ommanney, Frederick Francis, New Bridge Foundry, Adelphi Street, Salford, Manchester.
1847. Owen, William, Phœnix Works, Rotherham.

1859. Paquin, Jean François, Locomotive Superintendent, Madrid Saragossa and Alicante Railways, Madrid, Spain.
1860. Parkin, John, Harvest Lane Steel Works, Sheffield.

1847. Peacock, Richard, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1848. Pearson, John, 1 Manchester Buildings, 7 Old Hall Street, Liverpool.

1859. Peet, Henry, London and North Western Railway, Locomotive Department, Wolverton.

1861. Perkins, Loftus, 3 Oberhafenstrasse, Hamburg: (or care of A. M. Perkins, 6 Francis Street, Regent's Square, London, W.C.)

1856. Perring, John Shae, 104 King Street, Manchester.

1863. Perry, Thomas J., Highfields Engine Works, Bilston.

1860. Peyton, Edward, Bordesley Works, Birmingham.

1856. Piggott, George, Birmingham Heath Boiler Works, Birmingham.

1854. Pilkington, Richard, Jun., 10 Coburg Place, Upper Kennington Lane, London, S.

1859. Pitts, Joseph, Old Foundry, Stanningley, near Leeds.

1859. Platt, John, Hartford Iron Works, Oldham.

1862. Player, John, Norton, near Stockton-on-Tees.

1861. Plum, Thomas William, 3 East India Avenue, London, E.C.

1856. Pollard, John, Midland Junction Foundry, Leeds.

1860. Ponsonby, Edward Vincent, Engineer, Great Western Railway, Worcester.

1852. Porter, John Henderson, Ebro Works, Tividale, near Tipton.

1861. Porter, Robert, Ebro Works, Tividale, near Tipton.

1864. Potts, Benjamin Langford Foster, 150 Camberwell Grove, London, S.

1851. Potts, John Thorpe, 150 Camberwell Grove, London, S.

1856. Preston, Francis, Ancoats Bridge Works, Ardwick, Manchester.

1862. Rake, Alfred Stansfield, Royal Victoria Dockyard, Passage West, near Cork.

1864. Ramage, Robert, Locomotive Superintendent, Midland Great Western Railway, Dublin.

1847. Ramsbottom, John, Locomotive Superintendent, London and North Western Railway, Crewe.

1860. Ransome, Allen, Jun., Messrs. Worssam and Co., King's Road, Chelsea, London, S.W.

1862. Ransome, Robert James, Orwell Works, Ipswich.

1862. Ravenhill, John R., Glass House Fields, Ratcliff, London, E.

1859. Rennie, George Banks, 39 Wilton Crescent, Belgrave Square, London, S.W.

1862. Reynolds, Edward, Don Steel Works, Sheffield.

1863. Richards, Edwin, Nantyglo Iron Works, near Newport, Monmouthshire.

1856. Richards, Josiah, Abersychan Iron Works, Pontypool.

1863. Richardson, Edward, Engineer, Lyttelton, New Zealand.

1858. Richardson, Thomas, Hartlepool Iron Works, Hartlepool.

1859. Richardson, William, Hartford Iron Works, Oldham.

1863. Rigby, Samuel, Cock Hedge Mill, Warrington.

1848. Robertson, Henry, Great Western Railway, Shrewsbury.

1859. Robinson, John, Messrs. Sharp Stewart and Co., Atlas Works, Manchester.

1853. Ronayne, Joseph P., 4 Harbour Hill, Queenstown.

1856. Rouse, Frederick, Great Northern Railway, Locomotive Department, Leeds.

1857. Routledge, William, New Bridge Foundry, Adelphi Street, Salford, Manchester.

1860. Rumble, Thomas William, 6 Broad Street Buildings, New Broad Street, London, E.C.

1847. Russell, John Scott, 20 Great George Street, Westminster, S.W.

1863. Ryder, William, Bark Street, Bolton.

1859. Sacré, Charles, Locomotive Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.

1864. Said, Colonel M., Bey, Ottoman Embassy, Bryanston Square, London, W.

1859. Salt, George, Saltaire, near Bradford, Yorkshire.

1864. Samuda, Joseph D'Aguilar, Iron Ship Building Yard, Isle of Dogs, Poplar, London, E.

1848. Samuel, James, 26 Great George Street, Westminster, S.W.

1857. Samuelson, Alexander, 27 Cornhill, London, E.C.

1857. Samuelson, Martin, Scott Street Foundry, Hull.

1861. Sanderson, George Grant, Parkgate Iron Works, Rotherham.

1864. Sanderson, John, Locomotive Superintendent, Whitehaven Cleator and Egremont Railway, Moor Row, near Whitehaven.

1860. Schneider, Henry William, Ulverstone Hæmatite Iron Works, Barrow, near Ulverstone.

1858. Scott, Joseph, Messrs. R. & W. Hawthorn, Forth Banks, Newcastle-on-Tyne.

1861. Scott, Walter Henry, Mauritius Railways, Locomotive Department, Port Louis, Mauritius: (or care of Joseph Reid, 49 Arundel Square, London, N.)

1864. Seddon, John, 31 King Street, Wigan.

1857. Selby, George Thomas, Smethwick Tube Works, Birmingham.

1850. Shanks, Andrew, 6 Robert Street, Adelphi, London, W.C.

1863. Sharp, Henry, Bolton Iron and Steel Works, Bolton.

1862. Sharpe, William John, 1 Victoria Street, Westminster, S.W.

1864. Shaw, Duncan, Mining Engineer, Cordova, Spain.

1856. Shelley, Charles Percy Bysshe, 21 Parliament Street, Westminster, S.W.

1861. Shepherd, John, Union Foundry, Hunslet Road, Leeds.

1859. Shuttleworth, Joseph, Stamp End Iron Works, Lincoln.

1851. Siemens, Charles William, 3 Great George Street, Westminster, S.W.

1862. Silvester, John, Messrs. George Salter and Co., Spring Balance Works, Westbromwich.

1862. Simpson, William, Conservative Club, St. James' Street, London, S.W.
1847. Sinclair, Robert, Great Eastern Railway, Stratford, London, E.
1857. Sinclair, Robert Cooper, 19 Temple Street, Birmingham.
1859. Slater, Isaac, Gloucester Wagon Company, Gloucester.
1853. Slaughter, Edward, Avonside Engine Works, Bristol.
1854. Smith, George, Wellington Road, Dudley.
1860. Smith, Henry, Brierley Hill Iron Works, Brierley Hill.
1858. Smith, Isaac, 36 Lancaster Street, Birmingham.
1860. Smith, John, Brass Foundry, Traffic Street, Derby.
1857. Smith, Josiah Timmis, Ulverstone Hæmatite Iron Works, Barrow, near Ulverstone.
1859. Smith, Matthew, Caledonia Wire Mills, Halifax.
1860. Smith, Richard, Berry Hill, Lichfield.
1857. Smith, William, 19 Salisbury Street, Adelphi, London, W.C.
1863. Smith, William Ford, Gresley Iron Works, Ordsal Lane, Salford, Manchester.
1857. Snowdon, Thomas, 147 High Street, Stockton-on-Tees.
1859. Sokoloff, Capt. Alexander, Engineer, Russian Imperial Service, Steam Marine Department, Cronstadt, Russia: (or care of Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.)
1863. Somerville, Wallace Cochrane, 15 Vassal Road, North Brixton, London, S.
1858. Sörensen, Bergerius, Engineer-in-Chief, Royal Norwegian Navy Department, Horten Dockyard, Norway: (or care of Messrs. Tottie and Sons, 2 Alderman's Walk, Bishopsgate Street, London, E.C.)
1859. Spencer, John Frederick, 3 St. Nicholas Buildings, Newcastle-on-Tyne.
1853. Spencer, Thomas, Old Park Works, near Shiffnal.
1854. Spencer, Thomas, Newburn Steel Works, Newcastle-on-Tyne.
1864. Spittle, Thomas, Cambrian Iron Foundry, Newport, Monmouthshire.
1862. Stableford, William, Oldbury Carriage Works, near Birmingham.
1859. Stewart, Charles P., Messrs. Sharp Stewart and Co., Atlas Works, Manchester.
1851. Stewart, John, Blackwall Iron Works, Russell Street, Blackwall, London, E.
1864. Stokes, James Folliott, Resident Engineer, West Shropshire Mineral Railway, Meole Brace, Shrewsbury.
1857. Stokes, Lingard, 36 Carey Street, Lincoln's Inn Fields, London, W.C.
1863. Storey, John Henry, Knott Mill Brass and Copper Works, Little Peter Street, Manchester.
1862. Strong, Joseph F., Resident Engineer, East Indian Railway, Cawnpore, India.
1861. Sumner, William, 21 Clarence Street, Manchester.
1860. Swindell, James Evers, Parkhead Iron Works, Dudley.

1864. Swindell, James Swindell Evers, Cradley Iron Works, near Brierley Hill.
1859. Swingler, Thomas, Victoria Foundry, Litchurch, near Derby.

1861. Tangye, James, Cornwall Works, Clement Street, Birmingham.
1859. Tannett, Thomas, Victoria Foundry, Leeds.
1861. Taylor, George, Clarence Iron Works, Leeds.
1858. Taylor, James, Britannia Engine Works, Cleveland Street, Birkenhead.
1862. Taylor, John, Mining Engineer, 6 Queen Street Place, Upper Thames Street, London, E.C.
1862. Taylor, Richard, Mining Engineer, 6 Queen Street Place, Upper Thames Street, London, E.C.
1864. Thomas, Thomas, Clyde House, Canton, Cardiff.
1857. Thompson, John Taylor, Messrs. R. and W. Hawthorn, Forth Banks, Newcastle-on-Tyne.
1857. Thompson, Robert, Haigh Foundry, near Wigan.
1862. Thompson, William, Spring Gardens Engine Works, Newcastle-on-Tyne.
1852. Thomson, George, Crookhay Iron Works, Westbromwich.
1861. Thwaites, Robinson, Vulcan Iron Works, Thornton Road, Bradford, Yorkshire.
1862. Tijou, William, 9 Great George Street, Westminster, S.W.
1861. Tipping, Isaac, H. M. Gun Carriage Manufactory, Madras, India: (or care of H. Tipping, Bridgewater Foundry, Patricroft, near Manchester.)
1862. Tolmé, Julian Horn, 1 Victoria Street, Westminster, S.W.
1863. Tomlinson, Edward, Miles Platting Works, Elm Street, Manchester.
1857. Tomlinson, Joseph, Jun., Locomotive Superintendent, Taff Vale Railway, Cardiff.
1856. Tosh, George, Locomotive Superintendent, Maryport and Carlisle Railway, Maryport.
1860. Townsend, Thomas C., 16 Talbot Chambers, Shrewsbury.
1863. Townsend, William, West Orchard, Coventry.
1862. Troward, Charles, Great Northern Railway, Locomotive Department, Doncaster.
1856. Truss, Thomas, Great Western Railway, Carriage Department, Chester.
1859. Turner, Edwin, Bowling Iron Works, near Bradford, Yorkshire.
1856. Tyler, Capt. Henry Wheetley, R.E., Railway Department, Board of Trade, Whitehall, London, S.W.

1862. Upward, Alfred, Engineer, Chartered Gas Company, 146 Goswell Street, London, E.C.

1862. Vavasseur, Josiah, Bear Lane, Southwark Street, London, S.E.
1856. Vernon, John, Iron Ship Building Yard, Brunswick Dock, Liverpool.
1861. Vickers, Thomas Edward, Don Steel Works, Sheffield.

1856. Waddington, John, New Dock Iron Works, Leeds.
1856. Waddington, Thomas, New Dock Iron Works, Leeds.
1863. Wakefield, John, Great Southern and Western Railway, Locomotive Department, Dublin.
1864. Walker, Bernard Peard, Junction Cut Nail Works, Wolverhampton.
1861. Walker, John G., Netherton Iron Works, near Dudley.
1847. Walker, Thomas, Patent Shaft Works, Wednesbury.
1863. Walker, William Hugill, Wicker Iron Works, Sheffield.
1863. Wallace, William, Superintending Engineer, Montreal Ocean Steam Ship Company, Liverpool.
1864. Warden, Walter Evers, Phœnix Bolt and Nut Works, Glover Street, Birmingham.
1856. Wardle, Charles Wetherell, Boyne Engine Works, Hunslet, Leeds.
1852. Warham, John R., Iron Works, Burton-on-Trent.
1862. Watkins, Richard, Canal Iron Works, Millwall, London, E.
1862. Webb, Francis William, London and North Western Railway, Locomotive Department, Crewe.
1862. Webb, Henry Arthur, Bretwell Hall Iron Works, near Stourbridge.
1860. Weild, William, Queen's Chambers, Market Street, Manchester.
1862. Wells, Charles, Moxley Iron Works, near Bilston.
1862. Westmacott, Percy G. B., Elswick Engine Works, Newcastle-on-Tyne.
1856. Wheeldon, Frederick R., Highfields Engine Works, Bilston.
1864. White, Isaiah, Messrs. Portilla and White, Engineers and Iron Ship Builders, Seville, Spain.
1859. Whitham, James, Perseverance Iron Works, Kirkstall Road, Leeds.
1859. Whitham, Joseph, Perseverance Iron Works, Kirkstall Road, Leeds.
1863. Whitley, Joseph, New British Iron Works, Corngreaves, near Birmingham.
1847. Whitworth, Joseph, Chorlton Street, Manchester.
1852. Whytehead, William Keld, Engineer-in-Chief to the Government of Paraguay: 32 Cambridge Street, Eccleston Square, London, S.W.
1859. Wickham, Henry Wickham, M.P., Low Moor Iron Works, near Bradford, Yorkshire.
1859. Wickham, Lamplugh Wickham, Low Moor Iron Works, near Bradford, Yorkshire.
1847. Williams, Richard, Patent Shaft Works, Wednesbury.
1859. Williams, Richard Price, Stocksbridge Iron Works, Deepcar, near Sheffield.
1856. Wilson, Edward, Great Western Railway, Worcester.
1859. Wilson, George, Cyclops Steel and Iron Works, Sheffield.
1863. Wilson, John Charles, East India House, 5 Lime Street, London, E.C.
1852. Wilson, Joseph W., 9 Buckingham Street, Strand, London, W.C.
1857. Wilson, Robert, Bridgewater Foundry, Patricroft, near Manchester.
1860. Wilson, William, 3 Queen Square, Westminster, S.W.

1862. Winby, William Edward, Old Park Iron Works, Wednesbury.

1859. Winter, Thomas Bradbury, 28 Moorgate Street, London, E.C.

1863. Wise, Francis, Chandos Chambers, Buckingham Street, Adelphi, London, W.C.

1858. Wood, Nicholas, Hetton Hall, Hetton, near Fence Houses.

1848. Woodhouse, Henry, London and North Western Railway, Stafford.

1851. Woodhouse, John Thomas, Midland Road, Derby.

1861. Woodhouse, William Henry, 11 Great George Street, Westminster, S.W.

1858. Woods, Hamilton, Messrs. Allsopp and Sons, Burton-on-Trent.

1864. Worsdell, Thomas William, Berkley Street, Birmingham.

1860. Worssam, Samuel William, King's Road, Chelsea, London, S.W.

1860. Worthington, Samuel Barton, Engineer, London and North Western Railway, Manchester.

1859. Wright, Joseph, Metropolitan Carriage and Wagon Company, Saltley Works, Birmingham.

1860. Wright, Joseph, Neptune Forge, Tipton Green, Dudley.

1863. Wright, Owen, Broadwell Forge, Oldbury, near Birmingham.

1863. Wright, Peter, Railway Wheel Vice and Anchor Works, Dudley.

1853. Wymer, Francis W., Superintending Engineer, Tyne Steam Shipping Company, 13 North Shore, Newcastle-on-Tyne.

1861. Yule, William, Nevesky Foundry, St. Petersburg, Russia.

HONORARY MEMBERS.

1848. Branson, George, Belmont Row, Birmingham.

1864 Branson, Joseph W., Belmont Row, Birmingham.

1863. Brockbank, William, 87 Princess Street, Manchester.

1863. Butler, William, 15 Bilbao Street, Cadiz, Spain.

1851. Clare, Thomas Deykin, Carr's Lane, Birmingham.

1848. Crosby, Samuel, Leek Street, Birmingham.

1863. Fairbairn, John, Farnley Iron Works, Leeds.

1863. Fisher, John, Priory Street, Dudley.

1863. Forster, George Emmerson, Collingwood Chambers, Newcastle-on-Tyne.

1863. Hackney, William, Richmond Cottage, New Gough Road, Edgbaston, Birmingham.

1864. Hornblower, Joseph Wells, 14 Waterloo Street, Birmingham.

1860. Hutchinson, William, Blue Lias Lime Stone Offices, Lyme Regis.

1858. Lawton, Benjamin C., Benwell Grange, Newcastle-on-Tyne.

1859. Leather, John Towlerton, Leventhorpe Hall, near Leeds. (*Life Member.*)

1860. Manby, Cordy, Tower Street, Dudley.

1863. Nichols, William, Midland Copper Works, Guild Street, Burton-on-Trent.

1864. Parsons, Charles T., Ann Street, Birmingham.
1856. Pettifor, Joseph, Midland Railway, Derby.
1864. Peyton, Abel, Oakhurst, Church Road, Edgbaston, Birmingham.
1861. Ratcliff, Charles, Wyddrington, Edgbaston, Birmingham.
1863. Rigg, Arthur, The College, Chester.
1859. Sherriff, Alexander Clunes, Great Western Railway, Worcester.
1863. Storey, Thomas R., 17 Gracechurch Street, London, E.C.
1864. Tennant, John, St. Rollox Chemical Works, Glasgow. (*Life Member.*)
1864. Thornton, Falkland Samuel, Bradford Street, Birmingham.
1848. Warden, William Marston, Edgbaston Street, Birmingham.
1858. Waterhouse, Thomas, Claremont Place, Sheffield.
1862. Whitehead, William, Don Steel Works, Sheffield.
1863. Woolley, John, Marehay Colliery, Ripley, near Derby.

GRADUATES.

1850. Glydon, George, Spring Hill Tube and Metal Works, Eyre Street, Birmingham.
1861. Middleton, Henry Charles, Vulcan Iron Foundry, Summer Lane, Birmingham.

PROCEEDINGS.

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28 JANUARY, 1864.

The SEVENTEENTH ANNUAL GENERAL MEETING of the Members was held at the house of the Institution, Newhall Street, Birmingham, on Thursday, 28th January, 1864; ROBERT NAPIER, Esq., President, in the Chair.

The Minutes of the last General Meeting were read and confirmed.

The Secretary then read the following

ANNUAL REPORT OF THE COUNCIL.

1864.

The Council have great pleasure, on this the Seventeenth Anniversary of the Institution, in congratulating the Members on the very satisfactory progress and prosperous condition of the Institution.

The Financial statement of the affairs of the Institution for the year ending 31st December, 1863, shows a balance in the Treasurer's hands of £2365 15*s*. 10*d*. after the payment of the accounts due to that date. The Finance Committee have examined and checked the receipts and payments of the Institution for the last year 1863, and report that the following balance sheet rendered by the Treasurer is correct. (*See Balance Sheet appended.*)

The Council report with great satisfaction the continued increase in the number of Members that has taken place during the past year; the total number of Members of all classes for the year being 540, of whom 24 are Honorary Members, and 3 are Graduates, being an effective increase of 43 during the year.

The following deceases of Members of the Institution have occurred during the past year 1863:—

William Bagnall,	Westbromwich.
Alexander Brodie Cochrane,	Dudley.
John Farmer,	Dudley.
James Fenton,	Low Moor.
Joshua Field,	London.
Benjamin Gibbons, Jun.,	Birmingham.
Benjamin Goodfellow,	Hyde.
William Watson Hewitson,	Leeds.

The Council have particular pleasure in acknowledging the receipt of the handsome donation of Fifty pounds to the funds of the Institution from the President; and also in expressing their thanks to the Donors of the valuable and acceptable additions that have been presented to the Library during the past year. The Council wish to urge on the attention of the Members the important advantage of obtaining a good collection of Engineering Books, Drawings, and Models in the Institution, for the purpose of reference by the Members personally or by correspondence; and they trust this desirable object will be promoted by the Members generally, so that by their united aid it may be efficiently accomplished. Members are requested to present copies of their works to the Library of the Institution.

LIST OF DONATIONS TO THE LIBRARY.

Drawing of the Engines of the Frigate "Hector," by Robert Napier and Sons; from the President.

Official Illustrated Catalogue of the International Exhibition of 1862; from the Commissioners.

Mills and Millwork, by William Fairbairn; from the author.

Report on the Suez Canal, by John Hawkshaw; from the author.

On the Rolling of Ships, by William Froude; from the author.

On the Change of Form of Wrought Iron in Heating and Cooling, by Lt.-Col. Clerk, R.A.; from the author.

On the Density of Steam, by William Fairbairn; from the author.

On the Expansion of Superheated Steam, by William Fairbairn; from the author.

On the Construction of Marine Steam Boilers, by Charles Wye Williams; from the author.

On a new theory of the Generation of Steam, by E. J. Reed; from Mr. C. Wye Williams.

Proceedings of the Institution of Civil Engineers; from the Institution.

Report of the British Association for the Advancement of Science; from the Association.

Proceedings of the Royal Institution of Great Britain; from the Institution.

Proceedings of the French Institution of Civil Engineers; from the Institution.

Journal of the Architect and Engineer's Society for the kingdom of Hannover; from the Society.

Journal of the Board of Arts and Manufactures for Upper Canada; from the Board.

Report of the United States Patent Office; from the Commissioners.

Journal of the Royal United Service Institution; from the Institution.

Transactions of the Institution of Engineers in Scotland; from the Institution.

Proceedings of the South Wales Institute of Engineers; from the Institute.

Report of the Manchester Association for the Prevention of Steam Boiler Explosions; from the Association.

Transactions of the Royal Scottish Society of Arts; from the Society.

Report of the Royal Cornwall Polytechnic Society; from the Society.

Journal of the Society of Arts; from the Society.

The Engineer; from the Editor.

The Mechanics' Magazine; from the Editor.

The Civil Engineer and Architect's Journal; from the Editor.

The London Journal of Arts; from the Editor.

The Artizan Journal; from the Editor.

The Practical Mechanic's Journal; from the Editor.

The Mining Journal; from the Editor.

The Railway Record; from the Editor.

The Steam Shipping Journal; from the Editor.

Photograph of Locomotive for Swedish Railway; from Mr. John Manning.

Specimens of Malleable Cast Iron; from the President.

The Council have great satisfaction in referring to the number of Papers that have been brought before the meetings during the past year, and the practical value and interest of many of the communications and the discussions that took place upon them, which form a valuable addition to the Proceedings of the Institution. The Council request the special attention of the Members to the importance of their aid and co-operation in carrying out the objects of the Institution and maintaining its advanced position, by contributing papers on Engineering subjects that have come under their observation, and communicating the particulars and results of executed works and practical experiments that may be serviceable and interesting to the Members; and they invite communications upon the subjects in the list appended, and other subjects advantageous to the Institution.

The following Papers have been read at the meetings during the last year:—

On the Apparatus used for Sinking Piers for iron railway bridges in India; by Mr. Joseph F. Strong, of Allahabad.

On a Type Composing and Distributing Machine; by Mr. William H. Mitchel, of London.

On the Construction of Drawing Rollers for Spinning Machinery; by Mr. William Weild, of Manchester.

On the Locomotive Engines in the International Exhibition of 1862; by Mr. Daniel K. Clark, of London.

On the Construction of Iron Ships; by Mr. John Vernon, of Liverpool.

On the Effects of Surface Condensers on Steam Boilers; by Mr. James Jack, of Liverpool.

On the Mechanical Features of the Liverpool Water Works; by Mr. Thomas Duncan, of Liverpool.

On the Mechanical Ventilation and Warming of St. George's Hall, Liverpool; by Mr. William Mackenzie, of Liverpool.

On Machinery for the Manufacture of Plate Glass; by Mr. George H. Daglish, of St. Helen's.

Description of the new Iron Works at Grosmont; by Mr. Hiram C. Coulthard, of Blackburn.

Description of the Cornish Pumping Engine with Wrought Iron Beam and the Pit Work at Clay Cross Colliery; by Mr. William Howe, of Clay Cross.

On the Processes and Mechanical appliances in the manufacture of Polished Sheet Glass; by Mr. Richard Pilkington, Jun., of St. Helen's.

The Council have much pleasure in referring to the great success and interest of the Annual Provincial Meeting of the Institution held in Liverpool last summer, and in expressing their special thanks to the Local Committee and the Honorary Local Secretary, Mr. William Stubbs, for the excellent reception that was given to the Members of the Institution on that occasion; and also to the authorities of the London and North Western Railway Company for the free special train for the excursions, and the Cunard Company for the free special steamer for visiting the docks and other works on the river; and to the proprietors of the works that were so liberally thrown open to the inspection of the Members, for the valuable opportunity afforded to the Members for seeing their works, and for so hospitably entertaining the Members on the occasion. The Council look forward with much confidence to the important advantages arising from the continuance of these Meetings in different parts of the country, from the facilities afforded by them for the personal communication of the Members in different districts of the country, and the opportunities of visiting the important Engineering Works that are so liberally thrown open to their inspection on those occasions.

The President, Vice-Presidents, and five of the Members of the Council in rotation, will go out of office this day, according to the rules of the Institution; and the ballot will be taken at the present annual meeting for the election of the Officers and Council for the ensuing year.

SUBJECTS FOR PAPERS.

STEAM ENGINE BOILERS, particulars of construction—form and extent of heating surface—relative value of radiant surface in effect and economy—cost—consumption of fuel—evaporation of water—pressure of steam—density and heat of steam—superheated steam, simple or mixed with common steam—pressure gauges—safety valves—water gauges—explosion of boilers, and means of prevention—effects of heat on the metal of boilers, low pressure and high pressure—steel boilers—cast iron boilers—incrustation of boilers, and means of prevention—effects of surface condensers on the metal of boilers—evaporative power and economy of different kinds of fuel, coal, wood, charcoal, peat, patent coal, and coke—moveable grates, and smoke-consuming apparatus, facts to show the best plan, and results of working—plans for heating feed water—mode of feeding—circulation of water.

STEAM ENGINES—expansive force of steam, and best means of using it—power obtained by various plans—comparison of double and single cylinder engines—combined engines—compound cylinder engines—comparative advantages of direct-acting and beam engines—engines for manufacturing purposes—horizontal and vertical—condensing and non-condensing—

injection and surface condensers—air pumps—governors—valves—bearings, &c.—improved expansion gear—indicator diagrams from engines, with details of useful effect, consumption of fuel, &c.—contributions of indicator diagrams for reference in the Institution.

Pumping Engines, particulars of various constructions—Cornish engines, beam engines with crank and flywheel, direct-acting engines with and without flywheel—size of steam cylinder and degree of expansion—number and size of pumps, and strokes per minute—speed of piston—pressure upon pump—effective horse power and duty—comparison of double-acting and single-acting pumping engines—construction of pumps—plunger pumps—bucket pumps—particular details of different valves—india-rubber valves, durability and results of working—diagrams of lift of valves—application of pumps—fen-draining engines—comparative advantages of scoop wheels and centrifugal pumps, lifting trough, &c.—details of pit work of pumping engines at mines.

Blast Engines, best kind of engine—size of steam cylinder, strokes per minute, and horse power—details of boilers—size of blowing cylinder, and strokes per minute—pressure of blast, and means of regulation—construction of valves—improvements in blast cylinders—rotary blowing machines—indicator diagrams from air main and steam cylinder.

Marine Engines, power of engines in proportion to tonnage—different constructions of engines, double cylinder engines, trunk engines—use of steam jackets—dynamical effect compared with indicator diagrams—comparative economy and durability of different boilers, tubular boilers, flat-flue boilers, &c.—brine pumps, and means of preventing deposit—salinometers—weight of machinery and boilers—kind of paddle wheels—speed obtained in British war steamers, in British merchant steamers, and in Foreign ditto, with particulars of the construction of engines with paddle wheels, &c.—screw propellers, particulars of different kinds, improvements in form and position, number of arms, material, means for unshipping, bearings, horse power applied, speed obtained, section of vessel—governors and storm governors.

Rotary Engines, particulars of construction and practical application—details of results of working.

Locomotive Engines, particulars of construction, details of experiments, and results of working—consumption of fuel—use of coal and wood—consumption of smoke—heating surface, length and diameter of tubes—material of tubes—experiments on size of tubes and blast pipe—construction of pistons, valve gear, expansion gear, &c.—indicator diagrams—expenses of working and repairs—means of supplying water to tenders—locomotives for steep gradients and sharp curves—distribution of weight on wheels.

Agricultural Engines, details of construction and results of working—duty obtained—application of machinery and steam power to agricultural purposes—barn machinery—field implements—traction engines, particulars of performance and cost of work done.

Caloric Engines—engines worked by Gas, or explosive compounds—Electro-magnetic engines—particulars and results.

Hydraulic Engines, particulars of application and working—pressure of water—construction and arrangement of valves, relief valves—construction of joints—hydraulic rams.

Water Wheels, particulars of construction and dimensions—form and depth of buckets—head of water, velocity, percentage of power obtained—turbines, construction and practical application, power obtained, comparative effect and economy.

Wind Mills, particulars of construction—number of sails, surface and form of sails—velocity, and power obtained—average number of days' work per annum.

Corn Mills, particulars of improvements—power employed—application of steam power—results of working with an air blast and ring stones—crushing by rolls before grinding—advantages of regularity of motion.

Sugar Mills, particulars of construction and working—results of application of the hydraulic press in place of rolls—application of steam and water for extracting the last portion of saccharine matter—construction and working of evaporating pans.

Oil Mills, facts relating to construction and working, by stampers, by screw presses, and by hydraulic presses—particulars of crushing rollers and edge stones.

Cotton Mills, information respecting the construction and arrangement of the machinery—power employed, and application of power—cotton presses, mode of construction and working, power employed—improvements in spinning, carding, and winding machinery, &c.

Calico-Printing and Bleaching Machinery, particulars of improvements.

Wool Machinery, carding, combing, roving, spinning, &c.

Flax Machinery, manufacture of flax and other fibrous materials, both in the natural length of staple and when cut.

Rope-Making Machinery—hemp and wire ropes, comparative strength, durability, and cost—steel wire ropes.

Saw Mills, particulars of construction—mode of driving—power employed—particulars of work done—best speeds for vertical and circular saws—form of saw teeth—saw mills for cutting ship timbers—veneer saws—endless band saws.

Wood-Working Machines, morticing, planing, rounding, and surfacing—copying machinery.

Glass Machinery—manufacture of plate and sheet glass—construction of heating furnaces, annealing kilns, &c.—grinding and polishing machinery.

Lathes, Planing, Boring, Drilling, and Slotting Machines, &c., particulars of improvements—description of new self-acting tools—engineers' tools—files and file-cutting machinery.

Rolling Mills, improvements in machinery for making iron and steel—mode of applying power—use of steam hammers—piling of iron—plates—fancy sections—arrangement and speed of rolls—length of bar rolled—manufacture of rolled girders.

Steam Hammers, improvements in construction and application—friction hammers—air hammers.

Rivetting, Punching, and Shearing Machines, worked by steam or hydraulic pressure—direct-acting and lever machines—comparative strength of drilled and punched plates—rivet-making machines.

Stamping and Coining Machinery, particulars of improvements, &c.

Paper-Making and Paper-Cutting Machines, new materials and results.

Printing Machines, particulars of improvements, &c.—type composing and distributing machines.

Water Pumps, facts relating to the best construction, means of working, and application—velocity of piston—construction, lift, and area of valves.

Air Pumps, facts relating to the best construction, means of working, and application—velocity of piston—construction, lift, and area of valves.

Hydraulic Presses, facts relating to the best construction, means of working, and application—economical limit of pressure.

Rotary and Centrifugal Pumps, ditto ditto ditto.

Fire Engines, hand and steam, ditto ditto ditto.

Sluices and Sluice Cocks, worked by hand or hydraulic power, ditto.

Cranes, steam cranes, hydraulic cranes, pneumatic cranes, travelling cranes.

Lifts for raising railway wagons—hoists for warehouses—safety apparatus.

Toothed Wheels, best construction and form of teeth—results of working—power transmitted—method of moulding—strength of iron and wood teeth.

Driving Belts and Straps, best make and material, leather, gutta percha, vulcanised india-rubber, rope, wire, chain, &c.—comparative durability, and results of working—power communicated by certain sizes—frictional gearing, construction and driving power obtained—friction clutches—shafting and couplings.

Dynamometers, construction, application, and results of working.

Decimal Measurement—application of decimal system of measurement to mechanical engineering work—drawing and construction of machinery, manufactures, &c.—construction of measuring instruments, gauges, &c.

Strength of Materials, facts relating to experiments, and general details of the proof of girders, &c.—girders of cast and wrought iron, particulars of different constructions, and experiments on them—rolled girders—best forms and proportions of girders for different purposes—best mixture of metal—mixtures of wrought iron with cast.

DURABILITY OF TIMBER of various kinds—best plans for seasoning and preserving timber and cordage—results of various processes—comparative durability of timber in different situations—experiments on actual strength of timber.

CORROSION OF METALS by salt and fresh water, and by the atmosphere, &c.—facts relating to corrosion, and best means of prevention—means of keeping ships' bottoms clean—galvanic action, nature, and preventives.

ALLOYS OF METALS, facts relating to different alloys.

FRICTION OF VARIOUS BODIES, facts relating to friction under ordinary circumstances—facts on increase of friction by reduction of surface in contact—friction of iron, brass, copper, tin, wood, &c.—proportion of weight to rubbing surface—best forms of journals, and construction of axleboxes—wood bearings—water axleboxes—lubrication, best materials, means of application, and results of practical trials—best plans for oil tests—friction breaks.

IRON ROOFS, particulars of construction for different purposes—durability in various climates and situations—comparative cost, weight, and durability—roofs for slips of cast iron, wrought iron, timber, &c.—best construction, form, and materials—details of large roofs, and cost.

FIRE-PROOF BUILDINGS, particulars of construction—most efficient plan—results of trials.

CHIMNEY STACKS of large size—particulars, form, mode of building, cheapest construction, &c.—force of draught, and temperature of current.

BRICKS, manufacture, durability, and strength—hollow bricks, fire bricks, and fire clay—perforated bricks, cost of manufacture, and advantages—dry clay bricks—machines for brick making—burning of bricks.

GAS WORKS, best form, size, and material for retorts—construction of retort ovens—quantity and quality of gas from different coals—oil gas, cheapest mode of making—water gas, &c.—improvements in purifiers, condensers, and gasholders—wet and dry gas meters—self-regulating meters—pressure of gas, gas exhauster—gas pipes, strength and durability, and construction of joints—proportionate diameter and length of gas mains, and velocity of the passage of gas—experiments on ditto, and on the friction of gas in mains, and loss of pressure.

WATER WORKS, facts relating to water works—application of power, and economy of working—proportionate diameter and length of pipes—experiments on the discharge of water from pipes, and friction through pipes—strength and durability of pipes, and construction of joints—penetration of frost in different climates—relative advantages of stand pipes and air vessels—water meters, construction and working.

Well Sinking, and Artesian Wells, facts relating to—boring tools, construction and mode of using.

Tunnelling Machines, particulars of construction, and results of working.

Coffer Dams and Piling, facts relating to construction—cast iron sheet piling.

Piers, fixed and floating, and pontoons, ditto ditto

Pile Driving Apparatus, particulars of improvements—use of steam power—particulars of working—weight of ram and height of fall, total number of blows required—vacuum piles—compressed air system—screw piles.

Dredging Machines, particulars of improvements—application of dredging machines—power required and work done.

Diving Bells and Diving Dresses, facts relating to the best construction.

Lighthouses, cast iron and wrought iron, ditto ditto

Ships, iron and wood—details of construction—lines, tonnage, cost per ton—water ballast—steel masts and yards, and wire rope rigging—comparative strength and advantage of iron and wood ships.

Mining Operations, facts relating to mining—modes of working and proportionate yield—means of ventilating mines—use of ventilating machinery—safety lamps—lighting mines by gas—drainage of mines—sinking pits—mode of raising materials—safety guides—winding machinery—underground conveyance—stone breaking machines—mode of breaking, pulverising, and sifting various descriptions of ores.

Blasting, facts relating to blasting under water, and blasting generally—use of gun-cotton, &c.—effects produced by large and small charges of powder—arrangement of charges.

Blast Furnaces—shape and size—consumption of fuel—burden, make, and quality of metal—pressure of blast—horse power required—economy of working—improvements in manufacture of iron—comparative results of hot and cold blast—increased temperature of blast—construction and working of hot blast ovens—pyrometers—construction of tuyeres—means and results of application of waste gas from close-topped and open-topped furnaces—preparation of materials for furnace and mode of charging.

Puddling Furnaces, best forms and construction—worked with coal, charcoal, &c.—application of machinery to puddling.

Heating Furnaces, best construction—consumption of fuel, and heat obtained.

Converting Furnaces, construction of furnaces—manufacture of steel—casehardening, &c.—converting materials employed.

Smiths' Forges, best construction—size and material—power of blast—hot blast, &c.—construction of tuyeres.

Smiths' Fans and Fans generally, best construction, form of blades, &c.—facts relating to power employed and percentage of effect produced—pressure and quantity of air discharged—size and construction of air mains—mechanical ventilation and warming of public buildings.

Coke and Charcoal, particulars of the best mode of making, and construction of ovens, &c.—open coking, mixtures of coal slack and other materials—evaporative power of different varieties.

Railways, construction of permanent way—section of rails, and mode of manufacture—mode of testing rails—experiments on rails, deflection, deterioration, and comparative durability—material and form of sleepers, size, and distances—improvements in chairs, keys, and joint fastenings—permanent way for hot climates.

Switches and Crossings, particulars of improvements, and results of working.

Turntables, particulars of various constructions and improvements—engine turntables.

Signals for stations and trains, and self-acting signals.

Electric Telegraphs, improvements in construction and insulation—coating of wires—underground and submarine cables—mode of laying.

Railway Carriages and Wagons, details of construction—proportion of dead weight.

Breaks for carriages and wagons, best construction—self-acting breaks—continuous breaks.

Buffers for carriages, &c., and station buffers—different constructions and materials.

Couplings for carriages and wagons—safety couplings.

Springs for carriages, &c.—buffing, bearing, and draw springs—range, and deflection per ton—particulars of different constructions and materials, and results of working.

Railway Wheels, wrought iron, cast iron, and wood—particulars of different constructions, and results of working—comparative expense and durability—wrought iron and steel tyres, comparative economy and results of working—mode of fixing tyres—manufacture of solid wrought iron wheels.

Railway Axles, best description, form, material, and mode of manufacture.

The Papers are to be written in the third person, on foolscap paper, on one side only of each page, leaving a clear margin of an inch width on the left side. In the subjects of the papers, extracts from printed publications and questions of patent right or priority of invention are not admissible.

The Diagrams to be on a large scale and strongly coloured, so as to be clearly visible to the meeting at the time of reading the paper. Enlarged details to be added for the illustration of any particular portions, drawn full size or magnified, with the different parts strongly coloured in distinctive colours. Several explanatory diagrams drawn roughly to a large scale in dark pencil lines and strongly coloured are preferable to a few small-scale finished drawings. The scale of each diagram to be marked upon it.

INSTITUTION OF MECHANICAL ENGINEERS.

BALANCE SHEET.

For the year ending 31*st December*, 1863.

Cr.	£	s.	d.
By Balance 31st December, 1862	1781	17	11
„ Subscriptions from 40 Members in arrear	120	0	0
„ ditto from 481 Members for 1863	1443	0	0
„ ditto from 3 Graduates for 1863	6	0	0
„ ditto from 7 Members in advance for 1864	21	0	0
„ ditto from 2 Life Members	60	0	0
„ Entrance Fees from 58 New Members	116	0	0
„ Donation from President	50	0	0
„ Sale of Extra Reports	12	14	0
„ Interest from Bank	59	19	4
	£3670	11	3

Dr.				£	s.	d.
To Printing and Engraving Reports of Proceedings	468	15	6			
Less Authors' copies of papers, repaid	9	9	6	459	6	0
„ Stationery and Printing				50	2	11
„ Office Expenses and Petty Disbursements				50	3	11
„ Coals, Gas, and Water				21	8	6
„ Expenses of Meetings				39	10	9
„ Fittings and Repairs				24	10	2
„ Travelling Expenses				28	4	2
„ Parcels				5	12	0
„ Postages				55	16	3
„ Insurance				3	10	9
„ Salaries				450	0	0
„ Rent and Taxes				116	10	0
Balance 31st December, 1863				2365	15	10
				£3670	11	3

(Signed) EDWARD JONES,
WALTER MAY, } Finance Committee.

28*th January*, 1864.

MEMOIRS

OF MEMBERS DECEASED IN 1863.

William Bagnall was born at Darlaston, Staffordshire, on 4th April 1797, and at an early age entered the ironworks of his father, who was a coal and iron master at Westbromwich and Tipton: he became a partner in the works in 1828, together with four of his brothers, and took an active part in the practical management. In 1840 by the death of his elder brother he became the senior member of the firm of Messrs. John Bagnall and Sons, having extensive ironworks and collieries in South Staffordshire, the quality of the iron manufactured being known as the I B Crown brand: he also took great interest in the extensive schools established in connection with their works for the workpeople and their families. This position he continued to hold until his death, which occurred suddenly, after only a few hours' illness, at his residence at Handsworth near Birmingham, on 12th August 1863, at the age of sixty-six. He was elected a Member of the Institution in 1848.

Alexander Brodie Cochrane was born at Dudley on 10th February 1813, and at the age of seventeen was engaged at Messrs. Grazebrook's collieries and ironworks near Dudley, which were then under the management of his father. In 1838 he started a small ironfoundry at Bilston in conjunction with Mr. John Joseph Bramah; and in 1840, in conjunction with his father and Mr. Bramah, commenced the Woodside Iron Works near Dudley. Upon the death of Mr. Bramah the late Mr. Charles Geach became his partner, and afterwards also the late Mr. Archibald Slate; and he subsequently carried on these works in conjunction with his brother and son. Amongst the public works there executed were the castings for the Exhibition building of 1851, the Copenhagen gas and water works, the pipes for the Melbourne water works, the large caisson and dock gates for the Victoria docks, London, and several large iron bridges, including Westminster Bridge, the Charing Cross Railway bridges, and the Rochester road bridge and swing bridge. In 1853 Mr. Cochrane also entered upon large undertakings in the North of England, including collieries in Northumberland and Durham, and the Ormesby Iron Works at Middlesborough. He continued in the active management of these numerous concerns until prevented by serious ill health some years before his death. At the Woodside works he carried out successfully the application of coking in ovens to the Staffordshire slack, and read a paper before the Institution in May 1861 upon the nature of the process and the results obtained. He became a member of the Institution in 1847, the year of its commencement, and was for some years before his death a Vice-President of the Institution. His death took place on 23rd June 1863, after a long and severe illness, at his residence, Stourbridge, in the fifty-first year of his age.

John Farmer was born on 22nd January 1796 at Kingswinford near Dudley, and his first situation was at Messrs. Heywood's ironworks at Brockmoor; from whence, on the opening of the Shut End Iron Works by Messrs. Bradley and Co. in 1816, he was appointed manager of these works, and retained that position to the time of his death, which took place on 22nd August 1863, in the sixty-eighth year of his age. He was elected a member of the Institution in 1862.

James Fenton was born at Dunkenny in Forfarshire on 29th August 1815; and after leaving the Glasgow University was apprenticed as a mechanical engineer to Messrs. James Cook and Co. of Glasgow, and afterwards as a civil engineer to Mr. Blackadder of Glamis. His first appointment was under Mr. Brunel on the Great Western Railway at its formation in June 1837; after which he was appointed resident engineer and locomotive superintendent on the Manchester and Leeds Railway in 1841. In 1845 he became acting engineer of the Leeds and Thirsk Railway, for which the bill had just been obtained; but previous to the completion of the line he undertook in 1846 the management of the Railway Foundry, Leeds, where the well-known "Jenny Lind" class of locomotive engines were built from his designs: a class of engine which, on account of its simplicity of construction combined with its steadiness at a high speed, was extensively adopted for passenger engines. He also constructed and launched the large landing stage at New Holland for the steamboat ferry across the Humber to Hull. In 1851 he was appointed consulting engineer to the Low Moor Iron Company, a position which he retained to his death. He was elected a Member of the Institution in 1847, the year of its commencement, and took a very active part in promoting its interests; he was elected a Vice-President of the Institution in 1857 and re-elected in each year subsequent. He died on 22nd April 1863, in the forty-eighth year of his age, at Leamington, where he had for some time resided for the benefit of his health.

JOSHUA FIELD was born at Hackney in 1786, his father being an extensive corn merchant. After leaving school in 1802 he spent two years in the machinery department of Portsmouth dockyard, then recently commenced under the superintendence of General Sir Samuel Bentham, and afterwards a year in the Admiralty drawing office at Whitehall. He was then engaged by Mr. Maudslay as draughtsman upon the block machinery invented by the elder Brunel, which was then in course of construction by Mr. Maudslay, with whom he was thus brought into connection, and with whom he thenceforward continued, being first in the original factory in Margaret Street, Cavendish Square, which was removed in 1810 to the present site at Lambeth, where he became a partner in 1822. Steam navigation having been introduced about 1812, he was principally engaged in the manufacture of marine engines, first for paddle-wheel vessels and more recently for the large screw war steamers. His name is specially connected with the introduction of steam navigation, and with bringing to its present state of perfection the Marine Engine, in the improvement of which he took a very active part, from the early 10 horse power engines of the "Richmond" and "Regent" made in 1815, to the large horizontal screw engines of 1350 nominal horse power made by his firm in 1862 for the iron-plated frigate "Agincourt." He became a Member of the Institution in 1862, and died on 11th August 1863 at the age of seventy-six.

Benjamin Gibbons, Jun., was born on 20th May 1815 at Redland near Bristol, and was the youngest son of the late William Gibbons, who was largely connected with the iron and shipping interests of that port. He commenced business in the South Staffordshire iron district about 1840 by developing some of the fire-clay mines at Sedgley, and about 1844 began making the cinder pig iron for foundry purposes at the Corbyn's Hall Furnaces near Dudley, and afterwards continued to do so at the Millfield Furnaces. He subsequently carried on also many successful mining operations both in Staffordshire and Derbyshire, and in 1856 established the Soudley Furnaces in the Forest of Dean, where he made the Soudley brand of pigs. He was elected a Member of the Institution in 1860; and died at his residence, Birmingham, on 3rd September 1863, at the age of forty-eight, from the results of a slight accident.

Benjamin Goodfellow was born in 1811 at Rainow near Macclesfield, and began to work in a silk mill at the age of six years: on the removal of his parents to Hyde near Manchester, he worked at the Carrfield Mills, Floweryfield, until 1838, and was ultimately employed there as a mechanic upon the various machines used in spinning and weaving cotton. About two years later he established works of his own, for the manufacture of the steam-engine piston known by his name, and for general engineering work; being particularly successful in his arrangements of compound steam engines for economising fuel, which have been largely adopted in the cotton manufacturing districts. He was one of the original members of the Institution from its commencement in 1847; and died on 29th April 1863 in the fifty-second year of his age.

William Watson Hewitson was born at Newcastle-on-Tyne in 1815; and after serving his time at Messrs. Robert Stephenson and Co.'s works in that town he was for some time in the locomotive shops of Messrs. Fenton Murray and Jackson at Leeds. From thence he went to the locomotive works of Messrs. Kitson and Co. at Leeds, taking the position of manager and principal draughtsman; and in 1842 he became a member of that firm, and continued so until his death on 7th May 1863 at the age of forty-eight. He had made the locomotive engine his special study from his first connection with business; and during the last two years of his life rendered material assistance in the development of the system of steam ploughing, in connection with Mr. John Fowler. He was a Member of the Institution from 1848.

The CHAIRMAN congratulated the Members upon the growing prosperity of the Institution and the very satisfactory progress it had made in the number of Members and increase of funds, and in the value and interest of the papers communicated: he moved that the Report of the Council be received and adopted, which was passed.

The CHAIRMAN announced that the Ballot Lists had been opened by the Committee appointed for the purpose, and the following Officers and Members of Council were found to be duly elected for the ensuing year:—

PRESIDENT.

ROBERT NAPIER, . . .	Glasgow.

PAST-PRESIDENTS.

Ex officio permanent Members of Council.

SIR WILLIAM G. ARMSTRONG, .	Newcastle-on-Tyne.
JAMES KENNEDY, . . .	Liverpool.
JOHN PENN, ...	London.
JOSEPH WHITWORTH, . .	Manchester.

VICE-PRESIDENTS.

CHARLES F. BEYER, . . .	Manchester.
EDWARD A. COWPER, . .	London.
ROBERT HAWTHORN, . . .	Newcastle-on-Tyne.
SAMPSON LLOYD, . . .	Wednesbury.
HENRY MAUDSLAY, . . .	London.
JOHN RAMSBOTTOM, . .	Crewe.

COUNCIL.

ALEXANDER ALLAN, . . .	Perth.
JOHN ANDERSON, . . .	Woolwich.
FREDERICK J. BRAMWELL, . .	London.
CHARLES COCHRANE, . .	Dudley.
WALTER MAY, ...	Birmingham.
C. WILLIAM SIEMENS, . .	London.

Members of Council remaining in office.

DANIEL K. CLARK,	London.
WILLIAM CLAY,	Liverpool.
JOHN FERNIE,	Leeds.
SIR CHARLES FOX,	London.
GEORGE HARRISON,	London.
THOMAS HAWKSLEY,	London.
EDWARD HUMPHRYS,	London.
EDWARD JONES,	Wednesbury.
CHARLES P. STEWART,	Manchester.

TREASURER.

HENRY EDMUNDS,	Birmingham.

SECRETARY.

WILLIAM P. MARSHALL,	Birmingham.

The following New Members were also elected:—

MEMBERS.

DAVID CAMPBELL,	Liverpool.
WILLIAM THOMAS CARRINGTON,	London.
GEORGE HEATON DAGLISH,	St. Helen's.
CHARLES E. DARBY,	Wrexham.
EDWARD HENRY FOSTER,	Wednesbury.
ELIOT HOWARD,	London.

The following paper was then read:—

DESCRIPTION OF A MACHINE FOR BREAKING LIMESTONE AND ORE AT KIRKLESS HALL IRON WORKS.

By Mr. JOHN LANCASTER, of Kirkless Hall, Wigan.

This Stone Breaking Machine, which is the invention of Mr. Blake of Newhaven, Connecticut, is employed for breaking limestone and ore for blast furnaces and also stone for metalling roads. It is driven by steam power, and consists of a crushing hopper, in which the stone is broken between a pair of jaws, one fixed in the frame of the machine, and the other vibrating on a centre through a short distance, worked by an ordinary toggle joint and long lever which receives its motion from a crank shaft.

The machine is shown in Figs. 1, 2, and 3, Plates 1 to 3; Fig. 1 is a longitudinal section, Fig. 2 a plan, and Fig. 3 an end elevation.

The fixed jaw A, Fig. 1, Plate 1, against which the stone is crushed, is a vertical fluted block of cast iron, bedded in zinc in the end of the very strong cast iron frame of the machine, and held in its place by loose tapered cheek pieces B B, as seen in the plan, Fig. 2, which fit into recesses on each side of the hopper. The moveable jaw C is fluted on the breaking face to correspond with the fixed jaw, the ridges of the moveable jaw being opposite the grooves of the fixed jaw: and the moveable jaw is suspended from a large transverse pin above the frame. At the back of the moveable jaw to give the motion are two struts D D, in the form of flat cast iron plates extending the whole width of the jaw and bearing in the middle in the upright thrust bar E; this bears at the bottom upon the main lever F, the whole forming a horizontal toggle joint of simple construction and great strength. Figs. 4 and 5, Plate 3, show the thrust bar E of the toggle joint;

and Fig. 6 is a plan of one of the strut plates D. The main lever F, Fig. 1, has its fulcrum on a cross beam cast in the frame of the machine, and when lifted by the connecting rod and crank G at the outer end it presses forward the breaking jaw C by straightening the toggle joint. In the depression of the lever the jaw is drawn back ready for the next stroke by the india-rubber spring I.

The entire frame of the machine is in one single casting, and has feet cast upon it to stand upon a brick or stone foundation: the feet have bolt holes cast in them for the purpose of bolting the machine down to the foundation; in practice however it is found to require nothing besides its own weight, about 8 tons, to keep it steady in its place. It is fixed high enough to allow a railway wagon or a cart to be placed under the hopper to receive the broken material direct from the crushing jaws. The crank shaft G carries a flywheel H on each side of the machine, and also the driving pulley K, which receives a belt from the steam engine or shafting employed to drive the machine.

The moveable jaw C, Fig. 1, Plate 1, works on a round bar of iron, which passes loosely through it and forms the centre upon which it vibrates. Every revolution of the crank causes the lower end of the moveable jaw to advance towards the fixed jaw about ⅜ inch and return; and when the jaw is drawn back the stone in the hopper falls lower down to fill up the space caused by drawing back the jaw, and is then ready for the next bite of the jaws, and so on until the broken stone drops out at the bottom. The extent of motion of the crank end of the main lever F is 5½ inches, giving a total leverage of 14 to 1. The distance of the jaws apart at the bottom determines the size of the broken material, and can be altered at pleasure. A variation of ⅝ inch can be made by raising or lowering the screws which adjust the wedges L, thereby altering the abutment for the toggle joint. Further variations are made by changing the strut plates D, and putting in longer or shorter ones as may be required.

The writer first became acquainted with this stone breaking machine at the International Exhibition of 1862, where a working model of it was shown in action; and from its simplicity and the ease with which the model broke hard flint stones he was induced to obtain a machine from the inventor in America for the purpose of breaking iron ore and limestone at the Kirkless Hall Iron Works, Wigan. This machine was started in October 1862, and since that time has worked continuously. The size of the jaws is 20 inches long by 7 inches width of opening at the top; and this therefore represents the largest stone which the machine will break. The largest quantity of limestone broken in one day of 10 hours has been 120 tons, or at the rate of 12 tons per hour; but the average weight turned out in regular work is 100 tons per day, or 10 tons per hour.

In consequence of the economy and advantage found in using this machine as compared with hand labour, a second machine was procured by the writer from the English maker, Mr. Marsden of Leeds, which was started in August last. This was intended solely for limestone, having the jaws 20 inches long by 10 inches width of opening at the top, so as to enable a large stone to be thrown direct into the jaws without having to be broken previously by a hammer. This second machine is found to break about the same quantity of stone per day as the first one. The first machine is now used for reducing the size of any iron ore or other material which may require to be broken small for the blast furnaces; as well as for breaking furnace slag for road making.

From the experience obtained with the two machines the writer has found that the cost of breaking any material to about the size of road metal is 3*d.* per ton. This includes unloading the material out of wagons, and feeding it into the machine, together with the engine power and all expenses connected with the machine. The speed of the machine it is found should not be less than 200 strokes per minute. When the jaws are fixed as close as they can be, namely about 1 inch apart at the bottom, the yield is about 5 tons per hour; but when they are $1\frac{1}{2}$ to $1\frac{3}{4}$ inch apart at the bottom, the quantity already named of 10 to 12 tons per hour can be got through. The indicated horse power required to drive one machine of the largest size is 15 horse power.

The only parts of the machines at the writer's works which have been replaced up to the present time are the fixed and moveable jaws; these with constant work last about six months. It has been found that none but white or mottled iron with the fluted faces well chilled will stand the severe rubbing and crushing action which takes place. This is all the wear that is experienced in the working parts, except the ordinary wear of the brasses of the connecting rod and crank shaft. Fig. 7, Plate 4, shows a section of the jaws to a larger scale; and Figs. 8 and 9 are full size sections showing the different forms of teeth with which the jaws are made.

The special points of advantage found in this machine are its strength of construction, and small amount of wear and tear, in consequence of the parts that are subjected to the severe strain required for crushing stone being simple pressure pieces of cast iron, of an advantageous form for strength, and having large bearing surfaces and small extent of motion on the bearing surfaces. Also the only parts exposed to wear by the stone whilst being crushed are the two jaws, which are plain solid castings of 14½ and 5½ cwts. weight, without any fitting upon them, and readily taken out and renewed.

A working model of the stone breaking machine was shown in action, readily breaking up pieces of the hardest flint, limestone, and ironstone.

The CHAIRMAN remarked that the cost named in the paper of 3*d.* per ton for breaking stone and ore by the machine appeared very low, amounting to only 25*s.* for the average production that had been stated of 100 tons per day: and he enquired whether that covered the whole expense of working, including breaking and carting away.

Mr. **Lancaster** replied that the cost of 3*d*. per ton did not include carting the stone away, but covered all the other expenses of breaking.

Mr. E. A. **Cowper** enquired what was the cost of coal at the Kirkless Hall Works: the cost of 3*d*. per ton for breaking limestone and ore certainly appeared very low, if that included steam power, coals, and attendance, for working the machine which required 15 horse power to drive it.

Mr. **Lancaster** said all those expenses were covered by the cost of 3*d*. per ton, and the cost of coal at his works was 3*s*. 6*d*. per ton.

The **Chairman** enquired whether the machine was found to work slower with one kind of material than with another.

Mr. **Lancaster** replied that the iron ore at the Kirkless Hall Works was of a very hard quality and therefore worked rather slower in the machine than other ores, requiring a great deal of crushing to reduce it; but generally it was found that heavier materials passed through the machine quicker than lighter ones, their greater weight keeping them well down between the jaws of the machine.

The **Chairman** enquired whether the working model now exhibited of the machine was the same that was shown in the International Exhibition of 1862.

Mr. **Marsden** replied that the present model was similar to the one shown in the Exhibition, and was made at the same time, about five years ago, when he made several models of the machine for the purpose of introducing it into England and other countries. Even the small model now shown was powerful enough to break raw uncalcined flints quite easily, as was now seen; by setting the flywheel revolving with only a moderate start by the handle, the flints were broken into small bits immediately on dropping them into the jaws: whereas in any ordinary mill for grinding or crushing materials, if a flint stone got in it would stop the motion of the machine or break some part of it. When the present machine was used for breaking raw flints, it was necessary to keep the hopper covered, to prevent the pieces from flying out, unless the stone was fed in by a cartload at a time, so as to keep the hopper always full.

The **Chairman** asked whether the machine had been tried for breaking granite for macadamising roads.

Mr. **Marsden** replied there were about fifty of the machines now in use at granite quarries, breaking the granite chips for making roads, where the chips would otherwise be wasted or would have to be broken by hand labour at a cost of 2*s.* per ton. This was now done by the machine at the cost of 3*d.* per ton, and the broken stone was produced as fast as the carts could take it away. Many of the machines were also employed for crushing emery stone for grinding, in which a great saving was effected by their use, as they did not make anything like so much flour as the ordinary grinding machines. Hitherto it had been difficult to breathe in an emery mill, owing to the quantity of fine flour with which the air was impregnated; and the emery flour was the least valuable sort of emery, being the waste of the mill, as it was impossible to grind the emery down to any size of grain without also making the flour. The new machine however crushed the emery into the smallest pieces required for the grinding mill, with only a very small quantity of flour.

The **Chairman** enquired what was the size to which the emery was reduced by the crushing machine.

Mr. **Marsden** replied that the great expense and waste in emery mills was in reducing the large lumps of emery stone into pieces of the size suitable for the grinding mill, about the size of marbles, which could then be speedily ground to grain. The smallest machine he made, weighing about 3½ tons, broke the lumps into pieces rather smaller than marbles, as small as the bits produced by the working model now exhibited. The machine was also used for crushing tin, copper, or gold ores, and was found to have advantages over the ordinary stamps employed for the purpose; for in stamping these ores the stamps knocked all the matrix into a pulverised mass, and the practice was for this whole mass of material to be taken from the stamps to the washing apparatus, to remove the foreign matters mixed with it. But with the new machine 75 per cent. of the foreign matter crushed could be picked out at once, by having a revolving table under the machine with boys standing round it to pick the large pieces of stone off, leaving only 25 per cent. to be washed, instead of the whole mass; since the action of the machine was to open the seams and let the true metal go without pulverising.

The **Chairman** asked what was the cost of the machines.

Mr. **Marsden** replied that the cost of the largest machine, having the jaws 20 inches long by 10 inches width of opening at top, was £240 complete. The smallest machine on this construction, weighing 3½ tons, cost £140, and had been made in the United States before the machine was introduced into England; it was now at work at a whinstone quarry at Witton-le-Wear, breaking 40 tons per day of whinstone, and he had seen it break as much as 3½ to 4 cubic yards per hour. The largest machine he had made in America had the jaws 20 inches long by only 7 inches wide, instead of 10 inches width of opening as now made.

The **Chairman** enquired for what purpose the machine was employed in the first instance in America, and whether many breakages of the cast iron frame occurred before the proper strength was arrived at.

Mr. **Marsden** said he had had several breakages before the cast iron frame was made strong enough to stand the severe strain thrown upon it in crushing stone. The work upon which the machine was first employed in America was breaking stones in the central park in New York, in which there were from 5 to 7 miles of road to be made in 1858. A great quantity of stone was therefore required to be broken for these roads, and none was allowed to be laid on the road which would not pass through a ring of 2 inches diameter: the price paid for breaking the stone by hand labour was nearly 10*s.* per cubic yard. The first machine made was taken to the park, and broke the stone on contract for only 3*s.* per cubic yard, and at the end of the first three months it had earned enough by the saving at that rate to pay its entire cost, while at the same time the work was found to be done much better by the machine than it had previously been done by hand labour at more than three times the cost. The stones to be broken were boulders of hard blue trap rock, as hard as flint and considerably tougher, and the strain put upon the machine to break them was greater than anything that had been met with in breaking any other materials. By the action of the jaws of the machine indeed the hardest substances were gradually broken up into pieces, and in two instances hammer heads that had accidentally fallen into the jaws had been crushed to pieces. One of these accidents occurred with the machine at work in New York, while he was standing close to it; the hammer was used for knocking the stones down in the jaws of the machine if they were too large to enter, and the head got loose and came off the wood handle and fell into the jaws. It was a cast steel head weighing 28 lbs., and was crushed to pieces by the machine, which was enabled to effect this by the circumstance that the divergence of the jaws was sufficient to allow any very hard substance that got between them to slip up when the excessive pressure of the jaws in closing came upon it; but then, when the jaws opened again, it again fell down lower between them, a small portion being chipped off each time, and in that way by a continued nibbling action the hardest material was gradually broken small enough to fall through. The second hammer head that was destroyed in that manner was in the machine described in the paper at the Kirkless Hall Works; and he had recently seen another there also, which had fallen into the machine and showed the marks of the jaws upon it, but had been picked out before being crushed to pieces.

Mr. J. C. **Wilson** enquired what was the inclination of the jaws of the machine to each other.

Mr. **Marsden** replied that he had tried different inclinations of the jaws, and the moveable jaw was now placed at the inclination shown in the drawing, the fixed jaw being upright. The jaws were from 7 to 10 inches wide at the top and 2 inches or less at bottom, with a depth of from 18 to 24 inches from top to bottom, the inclination being kept in all cases the same.

Mr. J. C. **Wilson** enquired whether the machine would be suitable for granulating animal charcoal; the machinery at present in use for that purpose was very expensive.

Mr. **Marsden** thought if the charcoal were dry the machine would quickly break it up to any degree of fineness required.

The **Chairman** asked what was the make of the suspending pin on which the moveable jaw worked.

Mr. **Marsden** replied it was only a piece of common round rolled iron, not turned and with only sufficient dressing to prevent its being too rough for the jaw to work upon; the ends were flattened and keyed fast in the frame of the machine.

Mr. **Wilson Lloyd** enquired whether the cost of 3*d.* per ton which had been stated for breaking limestone at the Kirkless Hall Works included any charge for interest on the capital expended in the machine. That would affect the question as to the probability of this machine superseding hand labour for the purpose.

Mr. **Lancaster** said the cost of 3*d.* per ton did not include any charge for interest on capital or depreciation. It was merely the contract price for lifting the stone into the machine, putting the wagons under, and working the machine in the usual way; and that was the average cost for crushing ordinary materials.

Mr. **Wilson Lloyd** did not see, that being the case, how a saving could be effected by the machine as compared with hand labour, because at their own works at Wednesbury limestone was broken by hand labour at a cost of only 3¼*d.* per ton; and if a charge for interest on capital and depreciation were added to the cost of 3*d.* per ton in breaking limestone by the machine, that would bring up the cost to considerably above 3*d.* per ton. A great improvement for reducing the expense with the machine would be effected if it were made self-feeding: at present it appeared that every lump of material to be crushed had to be lifted by hand from the ground and thrown into the jaws of the machine; but if it were fed direct from the wagons by means of an inclined plane, the cost of working would be materially lessened.

Mr. **Lancaster** had not found he could get limestone broken by hand labour for so little as 3¼*d.* per ton at his works, and the cost by hand labour had been as much as 7*d.* per ton, in comparison with which the present cost of 3*d.* per ton with the machine was a great saving. The machine had also the important advantage of breaking the materials to a much more uniform size than could be done by hand labour, and uniformity in the size of the pieces suited the working of the blast furnace better than irregular lumps. Moreover with hand labour it was found that often in the night time the men in charge of the furnaces threw in lumps both of ore and limestone which were much too large, and interfered with the regular working of the furnace and the proper make of iron: but this could not be done when the machine was used, as the materials were constantly crushed by it to a uniform size. He enquired what was the size of the pieces that were broken by hand labour at the cost of 3¼*d.* per ton.

Mr. **Wilson Lloyd** said the limestone was broken by hand labour to pieces about 3 inches cube. As labour was growing very costly in South Staffordshire a machine for crushing limestone cheaply was a great desideratum; but he had expected to find the cost of breaking stone by the machine would probably be only about half as much as appeared to be actually the case.

Mr. **Lancaster** observed that the larger size of the pieces broken by hand labour would make a great difference in the expense of breaking; for the cost of breaking stone by hand labour to so small a size as 1½ inch was many times greater than in reducing it to 3 inches only.

Mr. **E. A. Cowper** thought the application of the machine to breaking the materials for blast furnaces was decidedly a step in the right direction, as it was very important to have the materials broken fine for the purpose; and the more intimately the ore and limestone were mixed in the furnace, the better would be the yield of iron and the more economical its production.

Mr. **Samuel Lloyd** enquired whether more dust was made in breaking limestone and ore by the machine than by hand labour, as the introduction of dust into a blast furnace was not advantageous: with hand labour he had found very little dust was left after breaking large quantities of material.

Mr. **Lancaster** replied that practically no dust was made by the machine, and the whole of the broken material was taken direct from the machine to the furnace without riddling or screening.

Mr. **Marsden** said he had tested the machine during the last five years, in reference to the quantity of dust that it made; and had found that in breaking hard material, such as hard limestone, the dust made by the machine was only about two thirds as much as that made in hand breaking. The machine was intended for breaking materials that were too hard to be suitable for breaking by hand and would cost too much if broken sufficiently small by hand; but softer stone might still be broken by hand at a cheap rate. In road making, the size of the stones laid down was of great importance to the durability and usefulness of the road: at present a newly macadamised road was not fit for some time for horses or vehicles to pass over, and by the time it became ready for use it was already half worn out, and in holes in some places; but if the stones were broken small enough to go through a 1½ inch ring, and then the chippings laid on the top of these, a compact road would be obtained ready for immediate use. By hand labour however it was of course impossible to get the stone broken so small as that, on account of the great expense, as breaking down stones to 1½ inch size was double the work of breaking them down to 2 inches size; and here therefore the machine had a decided superiority.

The **Chairman** enquired how many of the machines were now at work in England.

Mr. **Marsden** replied that there were now about fifty of the machines at work in this country, several of which were being employed to break stones for macadamising roads; some of these were in country districts where there was an agricultural engine at hand, which would otherwise be standing idle for a great part of the year. The machines were always made self-feeding wherever practicable, either by a slanting shoot when the stone was at a higher level, or by elevators to raise it from below into the jaws of the machine. One of the machines at a quarry had been fixed on the side of the hill, with an inclined shoot for the stones to pass direct into the machine, and by that mode of feeding one man could feed 100 tons of stone per day into the machine, thus doing what would be the work of four men if the stone were fed in by hand. With the addition of a tramway to bring up the wagons immediately under the machine, he had seen a train of twelve wagons loaded in twenty minutes, by merely lifting a trap door of the bin and letting the broken stone run into the wagons. And when the stone was quarried in the side of a hill and passed by a shoot direct into the jaws of the machine and thence into the wagons beneath, it was found that it could be broken and delivered fifty miles away by rail at less expense than it had formerly cost for loading and delivering the rough stone. Where the stone had to be lifted by hand into the jaws of the machine it generally cost an additional 1*d*. per ton. The machine at the Kirkless Hall Works was placed at a level part of the works, so that there was no facility in that case for making it self-feeding, as it could not be placed below the level of the materials to be crushed. All the stone had therefore to be lifted into the jaws by hand, and he had known as much as 30 tons per day thrown in by one man, at a cost of 2*s*. 6*d*. in that instance. That was the first machine put to work in England, and all the machines now in use in this country had been introduced since 1862.

Mr. J. **Ramsbottom** had seen the machine at work at the Kirkless Hall Works on the occasion of the Liverpool Meeting of the Institution last August, and was much struck with the simplicity of its construction and its low cost, and its excellent action in breaking the limestone and ore for the blast furnaces. He thought the machine might be applied with advantage to breaking stones for ballast for the permanent way of railways, where it would be a great improvement to have the ballast of uniform quality throughout, so as to form an even and durable road.

Mr. E. A. **Cowper** had also seen the machine at work in the North of England, employed in breaking blast-furnace cinder for making roads, in which it appeared very effective, though seeming to make rather too much dust in the process. With regard to the utility of breaking stones small for macadamising, he thought 2 inch stones were not too large for the purpose if a heavy roller were passed over the road, supposing the road had been softened by water or recently picked up. The effect of passing a roller over was to bring the flat sides of the triangular or pyramidal pieces of stone uppermost, and he had seen a macadamised road made in that way in beautiful condition after a heavy roller had been twice passed over it; the rolling of a road was thus a matter of great importance as a measure of economy, for it saved the great waste caused by the stones rolling about and being gradually ground away before they settled or became imbedded in the road. In the working of the machine he had occasionally seen hard stones become jammed, but they always gave way gradually under the constant crushing action of the machine, and were finally crushed to pieces without having strained or damaged the machine. This was readily explained by the consideration that the action of the jaws upon a substance too hard for them to crush entirely through was to crumble away the edges of the substance immediately in contact with the jaws, and then the broken particles reduced the friction between the surfaces and acted to some extent as a lubricator, allowing the hard substance to slip upwards in the jaws and relieve the pressure; and by this continual biting action he could understand how any substance which was not actually harder than the surface of the chilled cast iron jaws themselves might be gradually crumbled away and at last broken up.

Mr. **Marsden** remarked that there was a difference in the make of the jaws in the machines intended for breaking stones for roads, where it was desirable to avoid making dust, and in those used for crushing "bulldog" for lining puddling furnaces, where it did not matter making dust. For the latter purpose the teeth of the jaws were made flatter, the depth of the corrugations being only about $\frac{1}{2}$ inch, Fig. 8, Plate 4; whereas in the machines intended for breaking stones for roads the corrugations were made sharper, Fig. 9, projecting $\frac{3}{4}$ inch instead of $\frac{1}{2}$ inch, the teeth being spaced at the same pitch apart in both cases, $2\frac{1}{2}$ inches centre to centre. The point of the teeth was made flat for $\frac{1}{8}$ to $\frac{1}{4}$ inch breadth, with the edges just rounded off. One of the machines with the sharper teeth was now employed at a chemical works at Gateshead for crushing pyrites, where it was desired to make the least dust possible, and it had proved highly satisfactory for this purpose; other modes of crushing the material had previously been tried there, but they had all been found expensive and made a great deal of dust.

The **Chairman** moved a vote of thanks to Mr. Lancaster for his paper, which was passed.

The following paper was then read:—

DESCRIPTION OF A HORIZONTAL V PUMP.

By Mr. JOHN J. BIRCKEL, of Liverpool.

The Pump forming the subject of the present paper is shown in Figs. 1, 2, and 3, Plates 5 and 6, which represent a double pump of this kind as constructed at the Vauxhall Foundry, Liverpool. In this pump the barrel is horizontal and moves upon a stationary bucket, instead of the bucket moving within a stationary barrel as in an ordinary pump; and it is termed a V pump on account of the peculiar shape of both barrel and bucket. Fig. 1, Plate 5, is a transverse section through the two pump barrels, and Fig. 2 a longitudinal section of the pump through one of the barrels: Fig. 3, Plate 6, is a plan. Fig. 4, Plate 7, shows a longitudinal section of one of the barrels to a larger scale, and Fig. 5, Plate 8, is a corresponding transverse section.

The lower half A of the barrel, Figs. 1 and 2, Plate 5, acts as a stationary bed, being fixed water-tight to the foundation plate B; the working portions are planed true throughout their entire length, and the angle of the V is 90 degrees, as seen in the transverse sections, Figs. 1 and 5. The upper or sliding half C of the barrel is also planed true throughout its length inside, as well as upon its return flanges, which make a water-tight joint with the lower half A. The barrel is made complete by the two end covers D D, in each of which is an aperture closed by a leather flap valve E, Fig. 4, Plate 7; these covers are bolted on the sliding barrel C, and are fitted true by planed faces upon the V bed A, with which they make a water-tight joint. A handle F, Figs. 1 and 2, is fixed to the sliding barrel C for convenience of lifting it out of its seat. The stationary bucket G, Figs. 2 and 4, is fixed to the bed A, and makes a water-tight joint both with the bed A and with the sliding barrel C; it communicates by means of the central opening with the suction chamber H, Figs. 1 and 5, and opens at both ends into the pump barrel, each opening being provided with a leather flap valve I, Fig. 4. The bucket is thus made to answer as the suction valvebox, whereby the pump is rendered double-acting by means of only a single valvebox.

When the sliding barrel C, Fig. 4, Plate 7, is set in motion, the water is drawn into it at one end through one of the suction valves I; while at the same time the water contained in the other end of the barrel is discharged through the delivery valve E at that end. The delivery valves E are prevented from opening too far by the catches J; and a similar provision is made with the two suction valves I, which are connected together by a chain. The pump works in a cistern K upon the foundation plate B, Figs. 1 and 2, into which it delivers the water raised; and a continuous discharge takes place through the overflow spout L, which is placed at such a height as to keep all the joints of the pump constantly immersed in the water, thus making them air-tight. When it is desired to use the pump as a force pump, it is only necessary to close the top of the cistern, and provide a rising main from the cistern to the height at which the water is to be delivered.

The pump is either worked directly by a steam cylinder or by gearing; but the purposes for which it is best adapted, namely drainage and irrigation, render it generally more convenient and more profitable to work the pump direct by a steam cylinder. The piston rod of the latter is then prolonged and works through a stuffing-box into the cistern K, with a crosshead on the end of the rod for attaching it to the sliding barrel C, as shown in Figs. 2 and 3, Plates 5 and 6. In the double pump here shown, each barrel C is worked by a separate steam cylinder, and the general arrangement of the cylinders is similar to that adopted in locomotive engines, the two being coupled at right angles with a flywheel between them. The whole mechanism resting upon one foundation plate B is thus self-contained, and entails only a minimum outlay for foundations, whilst it may be easily shifted from one place to another.

The following practical advantages are considered to be attained by this construction of pump. By making the barrel and the bucket in the **V** shape, the working parts have a tendency to wear themselves true and tight, instead of wearing themselves out of truth and leaky as in the case of an ordinary cylindrical bucket pump; and it appears that in practice this is found to be the actual result of working. This is an advantage of great importance in countries where skilled mechanics are scarce, and where not only are frequent repairs expensive in themselves, but the stoppages caused thereby are a source of still greater loss.

It is also found in practice that the **V** pump makes a considerably better vacuum, and consequently raises a greater column of water than pumps of the ordinary construction. It may be assumed that a vacuum of 22 feet column of water is all that may be expected in regular work from an ordinary bucket pump; whereas it has been ascertained by actual trial at Liverpool with a **V** pump constructed at the Vauxhall Foundry that it creates a vacuum of 28 feet of water, showing a difference of 21 per cent. in its favour. This may however be accounted for by the ends of the sliding barrel C, Fig. 4, Plate 7, being allowed to move close up to the bucket G; and also by the joints being all constantly immersed in the water. The advantage thus obtained may in many cases be of great importance.

The **V** pump occupies considerably less space than an ordinary double-acting horizontal pump, the difference in length for pumps of the same stroke being about equal to the length of one valvebox. The construction of the **V** pump also allows ready access to all the parts, and renders any repairs easy, and to that extent less expensive. It is only necessary to lift up the sliding barrel C, Figs. 1 and 2, Plate 5, by means of the handle F, as it is not fixed down in any way, and the whole of the working parts are then immediately exposed to view.

In calculating the percentage of loss in useful work by the friction of the moving parts in this pump as compared with an ordinary bucket pump, the coefficient of friction of metal surfaces working under conditions similar to those of the sliding parts of the pump may be taken from Morin's experiments to be 0·16, that is the friction is 16 per cent. of the whole pressure on the rubbing surfaces. But in the present **V** pump where the rubbing surfaces are inclined to the horizon at 45 degrees, this coefficient has to be increased in the ratio of 1 to the square root of 2; and the corrected coefficient is therefore taken as 0·22, that is the friction is 22 per cent. of the sliding load. Hence if w represent the whole pressure of the vacuum in lbs. upon one foot length of the sliding barrel, and l the length of stroke of the barrel in feet, the mean pressure during the entire stroke will be $\frac{1}{2}\ w\ l$; and therefore the whole amount of friction to be overcome during a complete stroke is equal to $0{\cdot}22 \times \frac{1}{2}\ w\ l^2$, neglecting the weight of the sliding barrel itself.

Now taking the vacuum pressure on the sliding barrel in ordinary working to be 10 lbs. per square inch, the useful work performed in one stroke of 1 foot 4 inches with a bucket 11 inches square is

(11 ins. × 11 ins. × 10 lbs.) × 1·33 ft. = 1609 foot pounds.

And the inside width of the sliding barrel measured horizontally being 15½ inches, the work absorbed by friction is found by substituting the numerical values in the expression previously obtained ($0{\cdot}22 \times \frac{1}{2}\ w\ l^2$), and amounts to

0·22 × ½ (12 ins. × 15½ ins. × 10 lbs.) × $(1{\cdot}33 \text{ ft.})^2$ = 362 foot pounds.

which is equal to 22 per cent. of the useful work, 1609 foot pounds. The weight of the sliding barrel itself is about 350 lbs., equivalent to about 300 lbs. when immersed in water, which will give an additional friction of 0·22 × 300 lbs. × 1·33 ft. = 88 foot pounds, making the total loss by friction 362 + 88 = 450 foot pounds, or 28 per cent. of the useful work.

From the same data it may be calculated that in a common bucket pump the work absorbed by friction of the bucket is nearly 12 per cent., and it has been given by Rankine as 10 per cent. of the useful work, showing an advantage in favour of the common pump in friction; but in the writer's opinion the increased friction of the **V** pump as above ascertained is compensated for by the advantages attending this pump as already described. It should be borne in mind also that, since the work in friction of the sliding barrel increases as the square of the length of stroke, whereas the useful work increases only in the simple ratio of the stroke, the percentage of loss by friction will increase in proportion to the length of stroke, unless there is at the same time a proportionate increase in the area of the bucket. For instance, with a bucket 9 inches square and a stroke of 2 feet, the capacity of stroke would be the same as in the example above given, and the useful work would consequently be the same: but the percentage of the friction as compared with the useful work would then amount to 42 per cent. It therefore follows that the ratio of the side of the square bucket to the length of stroke, which in the pump shown in the drawings is 1 to 1⅓ nearly, should not be exceeded, but rather reduced. If for instance this ratio were made 1 to 1¼, the above loss of 28 per cent. by friction would be reduced to 24 per cent.

Six of the **V** pumps have been employed on the main drainage works in London for pumping out foundations, where there was a great quantity of sand mixed with the water, so that they were literally working and grinding in sand most of the time. These pumps were worked by power and used in the roughest possible manner; but they were nevertheless worked for more than six months before requiring any replaning. A number of these pumps worked by hand have also been in use for several years in farm yards, manure factories, and other places, without requiring any repairs, excepting where they are continually at work, and then only the valves require re-leathering.

The **Chairman** enquired whether the pump had been employed in other countries besides England.

Mr. **Birckel** replied that three or four of the pumps had been made for Egypt for the purposes of irrigation, and one of them, a pump of 6 horse power, had now been at work there for twelve months. In that country along the banks of the Nile the water had generally to be raised a height of from 22 to 28 feet for irrigating the land when the river was at its lowest level; and in that case therefore the pump now described came in very conveniently, because it could be fixed above the level of high water and would still raise the water by suction at all times from the river, even when the water was at its lowest point, without requiring to be shifted and refixed at a higher level when the water rose.

The CHAIRMAN observed that the principal advantage of the pump appeared to be the facility it afforded for getting at the working parts by simply lifting up the sliding barrel; and he asked whether the sliding barrel was made of cast iron or of brass, and whether it was not expensive in fitting up.

Mr. BIRCKEL replied that the whole of the pump was made of cast iron, and in the fitting up it was certainly more expensive than an ordinary pump, because the working faces instead of being bored had all to be planed and afterwards scraped a little. The entire cost however did not differ much from that of an ordinary pump, the pumps sent to Egypt having been supplied by preference on account of their special applicability to that particular case, without costing much more than ordinary pumps of the same power. Besides the facility of getting at the working parts, the other principal advantage of the V pump was the tendency of the rubbing faces to wear themselves true in working on account of their shape.

The CHAIRMAN suggested that there would probably not be much advantage in the trouble and expense bestowed on fitting up, after the pump had been at work for a time, on account of the wear of the rubbing faces, particularly if it were working in water that contained much sand.

Mr. BIRCKEL remarked that the object of planing and scraping the rubbing faces was that by their being made a good fit in the first instance there might be less chance of the sand getting into the pump.

The CHAIRMAN observed that the friction in the V pump must be considerably more than in the common pump, as had been stated; and he enquired whether this was compensated for by any greater percentage of useful effect in delivery of water.

Mr. BIRCKEL replied that the delivery of water by the V pump was 95 per cent. of the volume of the pump, giving only 5 per cent. loss of water, on account of the better vacuum obtained by the pump working immersed in water; whereas in ordinary bucket pumps he believed there was generally 10 per cent. loss.

Mr. F. J. **Bramwell** remarked that there appeared to be three advantages attributed to the construction of pump now described, as compared with an ordinary pump: namely facility of access to the working parts, tendency of the rubbing surfaces to wear true in work, and better vacuum obtained: but in none of these respects did he think the superiority of the new pump was satisfactorily substantiated. As regarded ease of access to the working parts, that advantage was lost as soon as the pump was used as a force pump; and even confining the question to suction pumps alone, he did not consider that an ordinary pump presented any real difficulty in the way of an examination of the working parts whenever anything got out of order. In reference to the rubbing surfaces wearing true in continued working, he thought that was at best only a slight advantage and not one that would compensate for the loss by friction, which must be much greater than in a common pump; moreover it appeared a question whether it would be found in practice that the wear was equal on the piston and on the edges of the sliding barrel. As to the vacuum obtained, he considered the case of the ordinary pump was understated when it was represented as not drawing more than 22 feet height of suction; and if both pumps were immersed in water he did not see how the present pump would do more than an ordinary one. There were hardly any stationary engines where the air pump was not immersed in water, and in all cases the vacuum was much greater than what would correspond to 22 feet column of water. In the present instance, in consequence of the barrel of the pump being the moving portion, the result of working it at all rapidly would be that a large amount of power would be uselessly spent in simply agitating the water in the tank. He therefore did not see any advantage in the new pump as compared with an ordinary pump.

Mr. **Birckel** said the advantage of ready access to the working parts was certainly lost when the pump was used as a force pump, owing to its then being covered in; and it was therefore not recommended to be used except as a suction pump. It was thought a practical advantage to have all the working parts exposed to view by simply lifting up the sliding barrel of the pump, instead of having to break water-tight joints in order to open the valveboxes at each end of an ordinary horizontal pump; and the small cushion of air that remained in the sliding barrel when it was put down again in its place was a trifling amount compared with the quantity left in the valveboxes of an ordinary pump when they were closed after examination.

Mr. H. **Woods** thought the height of lift that had been mentioned of ordinary pumps, 22 feet, was much below the average that was attained in practice. He had had one pump of ordinary construction at work for twelve months night and day, and the average height of lift had been 26½ to 27 feet; and he had no doubt that that height of lift could be relied upon with any ordinary well made pump.

Mr. **Birckel** did not think that, though it might be obtained with a pump in good order, 27 feet of lift could be practically relied upon with any safety as the height for an ordinary suction pump; whereas the V pump had drawn 28 feet of water whilst standing on the pier head at Liverpool, without being primed with water to start it, and with the tank completely empty.

Mr. H. **Maudslay** remarked that it was fortunate for the pump now described that the banks of the Nile at low water happened to be no higher than the pump could draw by suction, otherwise its advantage of facility of access would be lost. Vertical pumps for irrigation from the Nile had also been made by his own firm, of the ordinary construction; and where the banks were too high to lift the water by suction, the engine was fixed on the top of the bank, working the pump at a lower level by a long piston rod passing direct from the steam cylinder to the cylinder of the pump below. In pumping dirty water however it was difficult to keep ordinary pumps in working order, and in that respect the pump now described appeared advantageous and deserving of attention; in pumping up the sewage of London it had been found very efficient, the height to which the sewage had to be raised to reach the outlet being below the limit at which the pump would work as a suction pump.

He had seen the pump at work for this purpose, and also for pumping water out of excavations where it appeared to be raising a large quantity of sand with the water. There was however a great disturbance and splash of the water in which the pump was immersed, by the motion of the barrel sliding backwards and forwards, and that must absorb a large portion of the power to no purpose; but he had not the means of ascertaining the percentage of result to power employed.

Mr. **Bieckel** said the disturbance of the water was mainly owing to the discharge of the contents of the bucket into the tank at each stroke; and the speed of the bucket itself being not more than about 110 feet per minute, he thought it could not have any material effect in disturbing the water in the tank. The new pump was not expected by any means to supersede the ordinary pump, but was only regarded as particularly suitable for the special cases to which it had already been advantageously applied: for very large pumps he did not think it would prove efficient, on account of the increased size and weight of the sliding barrel and the consequent increased wear of the working parts.

Mr. J. **Penn** observed that in the new pump the pressure on the sliding barrel and consequently the friction of the working faces would increase with the height of lift, which was not the case in an ordinary pump packed with leather or having a solid bucket closely fitting the cylinder without packing.

Mr. **Bieckel** thought that in an ordinary pump having the bucket packed with leather the friction must be assumed to increase with the head of water, as he thought the pressure would act behind the packing to press it against the cylinder.

Mr. E. **Humphrys** did not think that was the case, and it was certainly not so with metallic-packed pistons, the friction of which did not increase, however much the pressure of water might be increased; whereas in the new pump the pressure on the sliding barrel was proportional to the height of lift, and would be still further increased if the pump were used as a force pump. On the whole he thought the construction of the pump was a step backwards rather than an improvement.

Mr. J. C. **Wilson** observed that, in reference to the alleged tendency of the sliding barrel to wear itself tight in working, he thought this would not be altogether the case; for at the bottom of the V in which it worked any sand and dirt from the water would be liable to lodge, and would cause the point of each end of the barrel to be ground away. He enquired what had been found to be the result of practice in this respect.

Mr. **Birckel** had not himself been acquainted with the working of the pumps for any length of time; but the pumps employed at the main drainage works in London, where there was much sand in the water, had worked six months before requiring any replaning.

Mr. E. **Humphrys** enquired why the new pump was stated to make a better vacuum than an ordinary pump: he considered if an ordinary pump were worked under water in the same way it would produce as good a vacuum.

Mr. **Birckel** had no doubt the vacuum would be as good in ordinary pumps if immersed in water, but they were not usually worked so, on account of the difficulty of getting to the working parts if permanently immersed; whereas the new pump was arranged to work always immersed in the water in the tank, and still have all the working parts readily accessible.

The **Chairman** asked what would be the advantage in working of the new pump over an ordinary one if both were immersed in water.

Mr. **Birckel** said probably the only advantage in that case would be the facility afforded by the construction of the new pump for coming home very close to the ends of the cylinder in each stroke, leaving not more than ½ inch clearance; as he believed a large space between the suction valve and the bucket was detrimental to the working of the pump, by preventing so good a vacuum from being obtained.

Mr. E. **Humphrys** thought that it was of no consequence whether the clearance were 1 inch or ½ inch, as that had no appreciable effect upon the vacuum. In a common pump working vertically the air would be discharged first, but in the new pump this would not be so perfectly effected.

Mr. E. A. **Cowper** considered it was a mistake to suppose the new pump had any advantage over the ordinary pump in respect of clearing itself of air by leaving only a small clearance at each end of the stroke: on the contrary he thought the advantage in this respect was on the side of the ordinary pump. For if the new pump were worked at all slowly, the air would accumulate along the top angle of the sliding barrel, and would not discharge itself with the water, on account of the horizontal position of the pump: but in an ordinary vertical pump, the air rising to the top of the water was the first to pass through the bucket, and thus the first thing the pump did in each stroke was to clear itself completely of air. Moreover in pumping water containing sand, if the sand did not lodge on the rubbing surfaces of the sides in the new pump, it would at least lodge in the bottom of the groove and cause the barrel to grind itself away at that part, and the wear would be much worse he thought than in an ordinary vertical pump packed in the usual manner, where no sand could lodge upon the sides of the barrel. For pumping very dirty water, such as sewage at drainage works or manure ponds in agricultural districts, the pump might be advantageous as affording a rough and ready means of getting at the working parts; but in other cases he thought the work would be done with less loss by friction and a smaller amount of wear and tear if an ordinary pump were employed.

Mr. **Birckel** observed that in the new pump the space at the end of the stroke for lodgment of air might be further diminished by making the end of the sliding barrel inclined at the same angle as the bucket, so that the quantity of air remaining in the pump would be reduced to the least amount.

The **Chairman** remarked that there must still be some air left in the pump, however small the clearance was made; but in the ordinary pump, as had been shown, no air whatever remained, the whole of it being expelled at the beginning of each stroke.

He proposed a vote of thanks to Mr. Birckel for his paper, which was passed.

The following paper was then read:—

ON THE IMPROVED TRAVERSING CRANES AT CREWE LOCOMOTIVE WORKS.

BY MR. JOHN RAMSBOTTOM, OF CREWE.

The Traversing Cranes described in the present paper are employed in the locomotive shops of the London and North Western Railway at Crewe, where they were designed and erected by the writer. They were seen in action by the members on the occasion of their visit to the Crewe works in the excursion at the Liverpool meeting of the Institution last summer. From the interest manifested in them on that occasion and the numerous enquiries that have since been made respecting them, the writer has thought that a description of the principle and construction of these cranes may be acceptable to the members.

There are seven of these cranes in use at the Crewe works, which have been working successfully for some time, the first having now been three years in constant work. They are driven by power and are so constructed as to be driven by a light endless cord of small diameter, extending throughout the entire length of the shop traversed by the crane. This cord is driven at a very high speed, nearly 60 miles an hour; in consequence of which only a very light driving pressure is required on the shifting gear of the crane. The driving cord is kept in uniform tension by the action of a constant weight; and is arranged so as to allow of the cranes working and traversing in every direction without sensibly affecting the length of the cord.

The cranes are of two classes: Longitudinal Overhead Traversers, of which there are two pairs in the engine repairing shop, lifting loads up to 25 tons; and Traversing Jib Cranes, of which there is one pair in the wheel shop, lifting 4 tons. The cranes are all driven by endless cords running along the top of the shops close to the roof tie-beams. The overhead traversers are worked in each case by a man seated on a platform attached to the crab and moving with it; and the jib cranes by a man standing below at the foot of the crane and walking along with it when traversing: each man having control over all the lifting, lowering, and traversing movements, by a set of handles.

The construction of the cranes is shown in Plates 9 to 18. Figs. 1 to 17, Plates 9 to 15, show the overhead traverser; and Figs. 24 to 32, Plates 16 to 18, the jib crane.

Fig. 1, Plate 9, is a transverse section of the engine repairing shop; and Fig. 2 is a plan, shortened in the direction of the length of the shop. The two pairs of Overhead Traversers A A and B B work on two parallel sets of rails, each having a span of 40 feet 7 inches and a longitudinal traverse of 270 feet. The girders forming the longitudinal rails are carried by the side walls and by columns at a height of 16 feet above the floor. The two pairs of traversers are separately worked by the endless cords C C and D D, each cord being carried down the side of the shop, and returning along the same side but at 4 feet lower level. The course of the cords is indicated by the arrows. In order to communicate motion to the traverser and crab, the driving portion of the cord is carried across each traverser to the further end and back again before passing on to the main driving pulley.

The cord is returned round a tightening pulley E, 4 feet diameter, at the end of the shop, Fig. 1, Plate 9, carried in a horizontal sliding frame F, as shown to a larger scale in Figs. 3 and 4, Plate 10. To this frame is connected a weight G, Fig. 1, for the purpose of giving the requisite tension to the driving cord, and taking up any stretching or temporary variation of length due to change of load or weather. The tightening frame F has a traverse across the end wall of the shop giving a range of 34 feet, which takes up a variation in the length of the cord equal to twice that amount.

The Traverser is shown in the side elevation and plan, Figs. 5 and 6, Plate 11; and Figs. 7 and 8, Plate 12, are transverse sections at the end and at the centre. It is constructed of two timber beams H H, trussed with wrought iron bars; and the whole is carried by four flanged wheels mounted in the cast iron carriages into which the ends of the beams H are fixed.

The Longitudinal Driving Gear is placed at J, Figs. 5 and 6, Plate 11, at the end of the traverser, and is shown to a larger scale in Fig. 13, Plate 14. It consists of a double friction-disc K, keyed on the vertical spindle of the driving pulley L in which the driving cord runs. The spindle footstep and guide M are carried by the double lever N, which is connected to the short lever on the horizontal shaft O. This shaft extends across the whole length of the traverser, as shown at O O in Figs. 10 and 12, Plate 13, and is under the control of the attendant by means of the lever I sliding on the shaft along with the crab, whereby the friction disc K, Fig. 13, is raised or lowered so as to be brought in contact with the friction pulley P either at bottom or at top, according to the direction in which the traverser is required to move. The motion of the friction pulley P is reduced by the worm and worm wheel and spur gear to the pinion shaft Q, which is carried across the traverser from end to end and by means of pinions drives the carrying wheels at each end of the traverser, Fig. 6. The frictional surfaces of the driving disc K are composed of rings of alder wood cut with the fibre on end; the edges of the wood rings are bevilled, and they are secured in their places by an inner iron ring, as shown black in Fig. 13.

The pulleys for returning the driving cord from the further end of the traverser are shown separately in Fig. 17, Plate 15. They work in the inclined positions shown, in order that the cord which has passed across the traverser may be returned at $1\frac{1}{2}$ inch lower level, and at the same time in a different vertical plane, as shown at A. This is done in order to facilitate the lowering and lifting movements, as afterwards described, and further in order that the two cords which are travelling in opposite directions may not rub against each other by the swagging of either of them. These pulleys are keyed upon wrought iron spindles running in long bearings, which are placed wholly below the pulleys, on account of the small amount of clearance between the roof principals and the pulleys, only 2½ inches. The weight of the pulley and spindle is taken by a brass footstep. The bearings are of cast iron, and are chambered at the top for the convenience of oiling, which is done by raising the pulley by hand until the spout of an ordinary oil can will reach the chamber. In the event of the cord leaving the pulleys from any cause, guards are provided, as shown at A, in order to prevent accident.

The Crab of the traverser is shown in Figs. 9 to 12, Plates 12 and 13, which give a transverse section, a longitudinal section, and a plan. It consists of a pair of cast iron frames, carrying the chain barrel, lifting and lowering, and traversing gear; the whole being carried upon four flanged wheels running on rails bolted upon the traverser beams H H.

The Lifting and Lowering Gear is partly shown in detail to a larger scale in Fig. 14, Plate 14. The double grooved pulley R is keyed to the vertical spindle, and is put in motion when the cord is pressed into either of its grooves by the presser pulleys S and T. These pulleys are of cast iron, 8 inches working diameter, and are mounted on short wrought iron studs tapped into the radial arm Z on which they are carried, as shown in Figs. 15 and 16, Plate 14, and in the plans, Figs. 11 and 12, Plate 13. The heads of the studs are recessed to form a receptacle for oil, Figs. 15 and 16, the oiling being done from the top, through a hole drilled in the stud for that purpose. When at rest the pulleys are clear of the cord, and are therefore only running when work is being done. The stud bearings are necessarily short, in consequence of the small amount of clearance between the pulleys and the roof tie-beams, which at this point does not exceed 1½ inches, as seen in Figs. 9 and 10. The grooves in the driving pulley R, Fig. 14, are of different diameters, whereby different velocities are obtained, the smaller being used for lowering and the larger for lifting; and as the two portions of the driving cord are running constantly in opposite directions, the reversing is obtained by simply pressing one or other of the cords into contact with the driving pulley, by the presser pulley S or T, on the same side of the driving pulley in both cases, with a pressure proportionate to the work to be done. The radial arm Z carrying the presser pulleys S and T turns upon the spindle A, Fig. 14; and the toothed segment B, which is part of the same casting as the arm Z, gears into a rack at the end of the rod C, Fig. 11, attached to the hand lever D. The lever D is under the control of the attendant, and is held in its place by a spring catch in a notched sector.

From the driving pulley R, Figs. 9 and 12, Plates 12 and 13, the velocity of the driving cord is transmitted and reduced through the worm and worm wheel U, Fig. 12. In order to economise space the shaft of the worm wheel U is carried through the hollow shaft on which the chain barrel V and its spur wheels are mounted. The number of revolutions is further reduced by a spur pinion and wheel to the shaft W, on which slide the two pinions X X of different diameters, gearing alternately into the spur wheels Y Y also of different diameters, which are keyed to the chain barrel V, so as to give a greater or less purchase as required for heavy or light loads, the ratio of difference being about 4 to 1.

The Cross Traversing Gear E, Fig. 12, Plate 13, is similar in principle to the lifting gear. The two grooves of the driving pulley F are however of the same diameter in this case, the velocity of traverse being the same in both directions. The pulley F is placed on the opposite side of the driving cord to the pulley R of the lifting gear, so that the cord when used for traversing may not foul the lifting pulley. The radial arm G carrying the presser pulleys belonging to the driving pulley F is worked by a rack and segment from the hand lever J, Fig. 11, which is adjacent to the hand lever D of the lifting and lowering motion.

The cross and longitudinal traversing movements are made at the rate of 30 feet per minute. The heavy loads are lifted at the rate of 1 foot 7½ inches per minute, and the light loads at the rate of 6 feet 5 inches per minute.

Fig. 24, Plate 16, is a transverse section of the wheel shop containing the pair of Traversing Jib Cranes; and Fig. 25 is a plan, shortened in the direction of the length of the shop. Figs. 26 and 27, Plate 17, are a vertical section and front elevation of one of the cranes. Each of the two jib cranes A A has a radius of 8½ feet, and a traverse of 120 feet along a single rail bolted to the floor; and is guided at the top by a pair of rolled girders B B, Fig. 27, of an ⊢⊣ section. The top of the crane carries the guide roller C, which just fits in between the two girders B and serves to support the crane laterally when lifting on either side of the rail. The driving cord is carried down the shop and back again, as indicated by the arrows in the plan, Fig. 25, just below the roof tie-beams. In its course it is passed round nearly half the circumference of the driving pulley D of each crane, by means of the two guide pulleys E E, the one crane being driven by the outgoing cord and the other by the return cord. The guide pulleys E are carried by a guide bracket upon the top of the crane post, Fig. 26, and traverse with the crane. The tightening gear F, Fig. 25, is similar in its action to that already described for the overhead traverser.

The crane is constructed of the plate box-frame G, Figs. 26 and 27, Plate 17, forming the base, and carrying the vertical cast iron pillar H, round which the outer casing and its attached jib K revolve. The driving pulley D is keyed to the vertical shaft I passing down the centre of the crane post, and from this shaft all the motions are taken by means of frictional gear. The lifting and lowering gear J, shown to a larger scale in Figs. 29 and 30, Plate 18, consists of the double friction-cone of cast iron L L, sliding on a fast key on the vertical shaft I, and moved up or down as required to bring the lower or upper frictional surfaces into contact with the single friction-cone M, from which the motion is transmitted and reduced through the worm wheel and train of spur gear to the chain barrel, as shown at J in Fig. 26. The whole is carried by the cast iron bracket N, which is bolted to the outer casing of the crane pillar and revolves with it. The bearings for the driving shaft I above and below the double friction-cone L are of cast iron; but the horizontal worm-spindle runs in a brass bush, Fig. 29, the end pressure when lifting being taken by the collar of the bush and the end step. The driving cones are raised or lowered by means of the double lever O O and brass clutches, as shown in the plan, Fig. 30, on each side of the boss of the lower cone L. These levers are placed under the cones instead of between them, in order that any oil thrown off the collars may not affect the frictional surface. The clutch levers are connected by an external rod to the hand lever P, Fig. 26, at a convenient height for the man working the crane.

The traversing motion shown at Q in Fig. 26, Plate 17, is shown to a larger scale in Fig. 31, Plate 18. It is similar in principle to the lifting gear, consisting of the single friction-cone R keyed on the bottom of the vertical driving shaft I, which communicates a backward or forward traverse when either face of the double cone S is brought into driving contact as required; the motion being transmitted to the carrying wheels by the horizontal shaft T through the trains of worm and spur gear indicated in Fig. 26. The traversing gear is applied to both the carrying wheels in order that there may be sufficient adhesion when the load overhangs either end of the crane, which would not be the case if only one wheel were driven and the load overhung the opposite end of the crane. The double cone S is moved along the horizontal shaft T by clutch levers U, Fig. 31, in a similar manner to the lifting and lowering gear, the clutch being worked by the hand lever V, Fig. 26. The double cones S, Fig. 31, are of cast iron: but the driving cone R is composed of a cone of alder wood, which is fastened by lock nuts and studs to a wrought iron disc screwed on the coned end of the vertical shaft I, as shown in the section, Fig. 32. The traversing gear is carried by the bracket W, Fig. 31, which is bolted to the foot of the centre pillar H, Fig. 26. The bearings of the horizontal shaft T are of cast iron; and the bearing of the foot of the driving shaft I is of brass, the weight of the shaft being taken by the collar of the bush, on which rest the lock nuts screwed on the shaft at that point, as shown in Fig. 31, forming an adjustable collar for taking up the wear and keeping the driving pulley D, Fig. 26, at the right level for the driving cord. The horizontal shaft T is carried at the ends by cast iron brackets, with brass bushes to take the end thrust in traversing: the worms are pinned on the shaft.

The jib K of the crane, Figs. 26 and 27, Plate 17, is formed of two wrought iron bars, stiffened laterally by diagonal trussing, and tied at the projecting end to the outer pillar of the crane by two tie rods. The bottom pressure of the jib is taken by the roller X, which is carried in a cast iron box bolted between the projecting sides of the outer casing of the crane, and runs on the bevilled base of the cast iron crane pillar H. The base G of the crane is sufficiently long to secure its stability when the maximum load is lifted over the rail, or lengthways of the crane base.

In these cranes, owing to the high speed at which the driving cord runs, the power is applied at a very long leverage over the load to be lifted. The velocity of the cord is in all cases 5000 feet per minute; and in the overhead traversers the heavy loads are lifted at the rate of 1 foot 7½ inches per minute, the total leverage being slightly over 3000 to 1; so that in this case the driving power required to lift the maximum load of 25 tons is only 18 lbs. irrespective of friction. When lifting light loads with the traversers the speed of lifting is increased to 6 feet 5 inches per minute, being a leverage of nearly 800 to 1; and in the jib cranes of the wheel shop, which lift up to 4 tons, the speed of lifting is 5 feet 1½ inches per minute, giving a leverage of nearly 1000 to 1. The actual power required in the traversers for lifting a load of 9 tons, besides the snatch block and chain, has been found to be 17 lbs. acting at the circumference of the driving pulley at the point where the driving cord acts upon it; and the total leverage over the load being 3000 to 1, the portion required to sustain the load is 6 lbs., leaving 11 lbs. as the working power required to overcome the friction of the crab gear under that load. The crab when unloaded is found to require a driving power of 1½ lbs. to overcome its friction.

The tightening weight G, Figs. 1 and 2, Plate 9, for the repairing shop traverser, is 218 lbs., or 109 lbs. on each half of the driving cord; and this is found to be about the best working strain, for keeping the rope steady and giving the required hold on the main driving pulley and the horizontal pulleys of the crab. The limit of the weight G is that required to give steadiness to the transverse portion of the cord situated between the crab pulleys and the end of the traverser, which is unsupported for a length of about 30 feet when the crab is close to one end of the traverser.

The driving cords employed are soft white cotton cords, $\frac{5}{8}$ inch diameter when new, and weighing about $1\frac{1}{2}$ ounce per foot: they soon become reduced to 9-16ths inch by stretching, and are found to last about eight months in constant work. In the overhead traverser which has been in constant work in the boiler shop for about three years with a single crab arranged to lift 6 tons, a smaller cord of about $\frac{3}{8}$ inch diameter was originally used; it was however found desirable to adopt a cord of $\frac{1}{2}$ inch diameter afterwards. The total length of each of the two driving cords in the repairing shop is 800 feet, in the wheel shop 320 feet, and in the boiler shop 560 feet. The wear and tear of the cord is considered to be mainly influenced by the bends to which it is subjected in its course; and the pulleys over which it is bent are therefore made none of them less than 18 inches diameter or about 30 times the diameter of the cord, excepting only the presser pulleys of 8 inches diameter for pressing the cord into the grooves of the driving pulleys in the overhead traversers. In the jib cranes the cord has eleven bends at all times, whether the two cranes are working or not; and in the repairing shop traversers the cord has twelve bends when both cranes are not working, sixteen when both are lifting or cross traversing alone, and twenty when both cranes are cross traversing and also lifting.

The groove of the driving pulleys is made V shaped at an angle of 30 degrees, and smaller at the bottom than the cord, as shown in the full size section, Fig. 21, Plate 15, so that the cord is gripped between the inclined sides and does not reach the bottom of the groove. In the guiding pulleys the groove is made half round at the bottom, with the same radius as the section of the cord, as shown in the full size section, Fig. 22; and in the presser pulleys the bottom of the groove is rounded out with rather a longer radius, as shown full size in Fig. 23.

The cord is supported at intervals of 12 to 14 feet by fixed slippers of a plain trough section, in which it lies whilst running, as shown in Figs. 18 and 19, Plate 15, and Fig. 28, Plate 17. They are of cast iron, flat in the bottom which is 1⅝ inch wide, and with side flanges, as shown in the full size section, Fig. 20; the ends are bell-mouthed, as shown in Fig. 19. These slippers are fixed 1½ inches below the working level of the cord on the driving side, as shown in Figs. 18 and 28, so that the driving wheels pass clear above the slippers in the traversing of the crane, and lift a portion of the cord out of them successively in passing.

In experiments made with a number of slippers carrying different weights the friction between the cord and the slipper was found to be about two-fifths of the load; but as the total weight of that portion of the cord which rests on slippers is only 50 lbs. and the whole friction consequently amounts to only 20 lbs., it is not considered worth while to complicate the system by the introduction of pulleys for supporting the cord. No care in oiling is required as regards these bearing slippers used in transmitting the power along the shop, as is the case in the power cranes driven by continuous longitudinal shafting where tumbling carriers are required, or where heavy cords at low velocities are used, requiring carrying pulleys, the bearings of which need regular oiling. By means of pull cords passing from end to end of the shop, the main driving gear for each pair of traversers can be stopped at any time by the men working the traversers; so that when the cranes are not working, the whole of the high speed gearing stands idle.

The diameter of the worm wheel U of the lifting gear in the 25 ton traversers, Fig. 14, Plate 14, is 24½ inches at the pitch line, and this is driven by a worm 3 inches diameter at the pitch circle with 1 inch pitch, the inclination of the threads of the worm to the axis of the worm wheel being 1 in 9½ (1 in 9·4). This is found to be safely within the angle of friction, so that the worm will not slip back with any weight that it has to lift; and it thus affords a complete means of holding up the weight at any point without the use of a break, and of lifting or lowering it instantly without the slightest jerk. The pitch of the worms has however been so arranged that in lowering but little power is required further than to put the gearing in motion. The speed of the worms at the pitch line is 833 feet per minute for the lifting gear of the 25 ton traverser, and 486 feet per minute in the jib cranes. The pressure on the teeth of the worm wheel in the traverser, when lifting the maximum load of 25 tons, is 9¼ cwts.; and in the jib crane, when lifting the load of 4 tons, it is 7½ cwts. In the practical working of the 25 ton traversers however the strain seldom exceeds one half the above amount, since in lifting locomotive engines the two crabs are usually employed in conjunction, for facility in slinging the engine.

The action of these cranes is very smooth and easy, and all the movements are readily under control.

Mr. Ramsbottom showed one of the cast iron slippers for carrying the driving cord of the crane, together with a piece of the cotton cord employed for the purpose, and also a piece that had been working on the 25 ton crane; it had not been in use many months, but was calculated from present experience to last about eight months before requiring renewal.

The Chairman enquired how long the cranes had been in use, and what was the reason for making the traversing cranes with wood trussed beams instead of wrought iron girders.

Mr. Ramsbottom replied that the jib crane in the wheel shop had been in use three years, and the traversing crane about four months. The traversing cranes were made with wood trussed beams merely to correspond in character with the cranes already employed in the shop. If all the cranes had now to be constructed afresh, no doubt iron would be used throughout in preference to wood. One point of great importance to the success of the crane had been to ensure all the pulleys being completely in balance, that they might run perfectly smooth and steady at the high velocities at which they had to be driven. This was done by balancing them carefully on a pair of parallel straight edges, adjusting their weight by a little filing and scraping, till they would remain at rest in any position indifferently, and when so adjusted they worked with great smoothness and steadiness. Without this complete balancing of the pulleys, the crane would have been a failure. In the jib cranes the driving pulleys of the lifting motion made as much as 1000 revolutions per minute; and it was by that means that the required power was obtained from so light a driving cord, and by simple contact of the cord with the pulleys, without its taking a turn round them. The friction cones for the travelling movement were made with hard wood surfaces, which were found to give a better bite than metal on metal; and there had been no difficulty in transmitting by them the full power required.

Mr. J. **Fernie** had had an opportunity of seeing the cranes in use, and was greatly pleased with their construction and action. The jib crane was most convenient for taking a pair of wheels out of the lathe and conveying it to any other spot with the least possible trouble; and the traversing crane also was of great advantage for lifting an entire engine and shifting it from one line of rails to another. He enquired whether any provision was made for preventing the driving cord from slipping off the several pulleys over which it passed, and whether any accident had occurred from that cause or from the rope breaking.

Mr. **Ramsbottom** replied that one accident had occurred with the 6 ton crane in the boiler shop not long after it began to be used, in consequence of the driving cord slipping off one of the pulleys, and sweeping the man off the crane platform. Now however guards had been added to the pulleys, as shown in the drawings, to catch the cord in the event of its slipping off, so as to prevent such an occurrence happening again.

The **Chairman** enquired what saving in labour had been effected in the wheel shop by the use of the new crane in place of the ordinary cranes used for such purposes.

Mr. Ramsbottom replied that there were previously two dozen pairs of blocks and ropes employed in the wheel shop, requiring a large number of labourers to work them; whilst now the two traversing jib cranes alone, with two men to work them, did the whole work of the shop and very much quicker than before; and £300 a year was saved in the piecework prices of the work done in that shop alone by the use of the new cranes.

The Chairman asked whether any difficulty had been found from the dust of the shops acting upon the cotton driving cord.

Mr. Ramsbottom replied there had been no difficulty from that cause: the cord was rubbed over at first with a little tallow and wax, and gave no trouble afterwards. It had been a question requiring some consideration in the first instance, what material should be used for the cord; whether leather, cotton, catgut, or hemp. He thought however nothing was so suitable for the purpose as a good cotton rope, properly made, on account of its lightness and suppleness. In using catgut the hook and eye forming the joint would give a very objectionable blow in passing over the pulleys at the high speed of running that was required.

Mr. R. Williams asked whether there was any difficulty in splicing the cotton rope.

Mr. Ramsbottom had not found any difficulty arise in splicing the cotton rope: in cotton spinning machinery it was regularly done, and a good workman would make a splicing which could scarcely be distinguished from the body of the rope itself.

The Chairman enquired whether there had been any trouble with the slippers in which the driving cord was supported between the pulleys; and what form of slipper had been found best.

Mr. Ramsbottom said he had first used a brass slipper, made narrower at the bottom than at the top and not giving the cord much room to play; but that shape did not answer, as the metal was found to become cut away too rapidly. Now however the slippers were made wider and flat bottomed, giving the rope free play, as it was found not at all necessary to confine it laterally. The metal now employed was also cast iron with the surface chilled, the chilled surface being smooth enough without any polishing: the friction was also less than with brass slippers.

The **Chairman** enquired whether the 25 tons load was allowed to descend freely in lowering the crane, and how the speed was checked in its descent.

Mr. **Ramsbottom** replied that the load descended by its own weight after being once started, and the speed was checked simply by applying the driving cord to the pulley of the winding drum, when a very slight pressure of the cord in the V groove of the pulley was sufficient to control the motion.

The **Chairman** enquired whether any experiments had been made to ascertain the actual friction of the crab in the traversing crane.

Mr. **Ramsbottom** replied that he had tried experiments upon the friction of the crab by attaching a small cord to the driving pulley, giving it a few turns round the pulley and carrying it over a fixed pulley so that weights could be hung on. It was then found that with a load of 8⅓ tons on the crab it required 17 lbs. weight at the driving pulley to start this load in raising it. The theoretical power required at the driving pulley to balance the load of 8⅓ tons was 6 lbs., showing that the friction of the worm and the rest of the gearing was 11 lbs. in that case, or nearly twice the theoretical power. The greater friction of the new crane as compared with ordinary cranes was indeed its only drawback; but that was more than compensated for by the simplicity of construction of the new crane, and the fact that in consequence of this increased friction it required no break to hold the load, which was an important advantage over the old cranes. Moreover if the cord were driven at a much lower velocity, in order to reduce the friction by diminishing the multiplying power of the crane, it would be necessary to put a much higher tension upon the cord, which would then have a tendency in the present arrangement of the driving gear to throw the crane out of line and cause it to run off the rails. It was therefore important to adhere to the high velocity of driving cord that had been already adopted.

Mr. E. A. **Cowper** observed that a light driving cord was the only plan compatible with a high speed of driving, as a heavy cord or chain would soon wear out by its own weight. The mode of reversing the motion, by merely deflecting the driving cord into one or other of the two grooves of the driving pulleys, was exceedingly simple and efficient; and the arrangement was also very simple for increasing the length of surface of contact of the cord with the pulley to meet the requirements of a heavier load. He enquired whether the weight of 17 lbs. at the driving pulley in the experiment that had been described was sufficient to start the crane.

Mr. **Ramsbottom** replied that the weight of 17 lbs. at the driving pulley of the crane was just insufficient to start the load of 8⅓ tons on the crab from a state of rest, but if once started it would keep it going, the theoretical force required to balance that load being only 6 lbs.

Mr. E. A. **Cowper** remarked that the friction of the crane in the experiment was illustrated by the skidding of an engine on the rails when the wheels had once started slipping; and probably in the case that had been described the actual friction of the crane when once in motion was not much more than 6 lbs. in addition to the theoretical power required to balance the load of 8⅓ tons; while from that force, 12 lbs., up to 17 lbs. at the driving pulley the crane would either run or stand. He enquired whether the jib cranes in the wheel shop were balanced by a load of ballast on the tail of the crane.

Mr. **Ramsbottom** replied that the jib cranes were not counterbalanced, the weight of the frame itself being sufficient to steady the crane under the heaviest loads it had to lift.

Mr. E. H. **Carbutt** enquired whether the cranes made much noise in working, on account of their high speed. He had seen a crane of similar construction at work in a foundry, and the noise it made was very objectionable.

Mr. **Ramsbottom** thought the noise in that case must have arisen from a want of balance in the moving parts; but in the present cranes, with the driving pulleys all properly balanced, there was no objection from noise, the cranes working very smoothly and quietly.

The **Chairman** proposed a vote of thanks to Mr. Ramsbottom for his paper, which was passed.

The Meeting then terminated.

PROCEEDINGS.

5 May, 1864.

The General Meeting of the Members was held at the house of the Institution, Newhall Street, Birmingham, on Thursday, 5th May, 1864; John Ramsbottom, Esq., Vice-President, in the Chair.

The Minutes of the last Meeting were read and confirmed.

The Chairman announced that the Ballot Lists had been opened by the Committee appointed for the purpose, and the following New Members were duly elected:—

MEMBERS.

William Coddington,	Blackburn.
Zerah Colburn,	London.
Edward Crowe,	Middlesborough.
John Dewhurst,	Sheffield.
Thomas Frost,	Derby.
Richard Heathfield,	Birmingham.
Thomas Henry Maudslay, Jun.,	London.
Sampson Moore,	Liverpool.
Colonel M. Said, Bey,	London.
John Sanderson,	Whitehaven.
John Seddon,	Wigan.
James Folliott Stokes,	Shrewsbury.
Bernard Peard Walker,	Wolverhampton.
Isaiah White,	Seville, Spain.
Thomas William Worsdell,	Birmingham.

HONORARY MEMBERS.

Joseph W. Branson, . . .	Birmingham.
Joseph Wells Hornblower, . .	Birmingham.
David Murray, ...	Birmingham.

The following paper, communicated through Mr. Charles F. Beyer of Manchester, was then read :—

DESCRIPTION OF HARRISON'S CAST IRON STEAM BOILER.

By Mr. ZERAH COLBURN, of London.

The importance of high pressure steam as a condition of steam engine economy has long been understood. Trevithick as early as 1804 worked an engine at what was then regarded as an enormous pressure, 50 lbs. per square inch. His American contemporary, Oliver Evans, recommended a still greater pressure, 150 lbs. per square inch, cut off at one third of the stroke; and from the records of the department for supplying Philadelphia with water, it appears that Evans actually employed not only this pressure, but still higher pressures, on the large scale of pumping engines. In 1817 one of his engines was started at the Fairmount Waterworks, Philadelphia, and was worked regularly at from 194 to 220 lbs. per square inch; the engine cylinder was 20 inches diameter and the stroke of the piston 5 feet, the usual working speed being 25 revolutions per minute; steam was supplied from four cylindrical boilers, 30 inches diameter and 24 feet long, fired externally. A Boulton and Watt engine of 44 inch cylinder and 6 feet stroke had been started two years previously at the same waterworks, having a cast iron boiler with vertical wrought iron flues, with a steam pressure of only 2½ to 4 lbs. per square inch. Both these engines pumped through a 16 inch main, 239 feet long, into a reservoir 102 feet above the level of supply. Trials of twenty four hours' duration showed that the low pressure engine had rather the advantage over the other in point of economy: the former pumped into the reservoir in twenty four hours 1,763,104 gallons of water with a consumption of 896 cubic feet of wood, being 1968 gallons per cubic foot; while the high pressure engine, in raising 3,124,891 gallons through the same main, consumed 1664 cubic feet of wood, or at the rate of 1878 gallons per cubic foot.

Steam of rather more moderate pressures than Evans employed, or of about 100 lbs. per square inch, continued subsequently to be employed in America, notwithstanding the frequent explosions of high pressure boilers. In England the boilers for Trevithick's engines were made of large diameter and of cast iron; and many of them were made at the Bridgenorth Foundry with an internal diameter of 8 feet, and in 8 feet lengths, which were connected together by flanges and bolts up to any length required. Such boilers were unquestionably dangerous, although many wrought iron boilers of equal or greater diameter and probably of less strength are worked up to the same pressure now. An occasional explosion of a Trevithick boiler, and the influence which the practice of Boulton and Watt then exercised, soon occasioned a general return to low pressures, except in Murray's, Stephenson's, and Hedley's locomotives, which were worked regularly at 50 lbs. per square inch.

Within the last thirty five years however, or in fact coincident with the progress of improvements in boiler making, there has been a corresponding tendency to return to high pressures. The locomotives on the Liverpool and Manchester Railway worked in 1830 with steam of 50 lbs.; by 1843, pressures of 75 lbs. and 80 lbs. had become common upon railways; 100 lbs. to 110 lbs. was regularly maintained in 1851; and at the present time 120 lbs. is the usual, and 160 lbs. an occasional pressure in locomotive boilers. The last named pressure is not very much below that recommended for locomotives by the late Jacob Perkins, nearly thirty years ago, who preferred steam of 200 lbs. cut off at one eighth of the stroke. In marine engines an ordinary working pressure of 25 lbs. has been reached, while some of the Liverpool and Montreal vessels are worked at 40 lbs., and the Pacific Mail steamers at 50 lbs. per square inch. For ordinary land engines even 100 lbs. pressure has been adopted in many cases; and this and still higher pressures are already employed by some makers of portable and traction engines.

Although the construction of boilers has been much improved, in order that higher and higher pressures might be maintained, it is certain that great room for improvement is yet left. The old boiler fired externally is objectionable; while for internal firing it is necessary either to have a firebox and tubes, or to have flues large enough to allow the fireplaces to be formed within them. The multitubular boiler, unless supplied with good water, requires much care to prevent choking with scale; and its repairs are in all cases greater than those of the Cornish and Lancashire boilers. The Lancashire or two-flued boiler is that most used in the manufacturing districts; but its diameter is necessarily so large as to render it imprudent in most cases to load it with steam of much more than 50 lbs. pressure, and this is not the high pressure to which present steam engine practice is tending. A diameter of 7 feet is common for Lancashire boilers; and if made of ½ inch Staffordshire plates, single-rivetted, their bursting pressure may be taken as 333 lbs. per square inch. This estimate is made upon Mr. Fairbairn's usual allowance of a loss of 44 per cent. in the strength of the solid plate at single-rivetted seams; and the estimate of course assumes that no flaws are hidden in the iron, and that the workmanship is good, the rivetting being fairly done so that the boiler shall not have been injured by the use of the drifting tool. This then is the limit of strength when the boiler is new; and it would be manifestly imprudent to press to more than 50 lbs. or at the utmost 70 lbs. a boiler which was certain to burst at 333 lbs., and to be permanently injured by a much lower pressure. It is shown moreover by the reports of the Manchester Boiler Association that many boilers are subject to weakening from corrosion or furrowing of the plates. A leakage of steam, however slight, from any part of the boiler into the adjacent setting is almost certainly attended with corrosion. Condensed steam, that is distilled water, appears to exercise a strong solvent power upon iron, as is known in the cases of boilers supplied with very soft water or peat water or more especially those fed with water from surface condensers. As has been shown in the case of several recent boiler explosions, the thickness of boiler plates is often wasted nearly through by unsuspected corrosion.

This source of danger to a certain extent neutralises the means occasionally resorted to for securing great strength in boilers, such as the use of steel or homogeneous metal plates, double rivetting, thick-edged plates, welded joints, &c.

Whenever a failure unhappily occurs in the plates or rivetting of a boiler, the destructive effect appears to depend, not merely upon the pressure under which the failure takes place, but also and probably still more upon the quantity of water contained in the boiler. The effect of the boiling water in an explosion may be considered as analogous to that of gunpowder; and, as in the case of gunpowder, the effect is proportionate to the quantity exploded. It is preferable therefore, while increasing the strain upon boilers by increasing the pressure of the steam, to diminish at the same time the quantity of water contained in them; doing so of course without exposing any part of the boiler to the direct action of the fire on one side of the plates where there is no water present on the other. In a large Lancashire boiler the object of carrying so much as from 15 to 20 tons of water is mainly to ensure that all the heating surfaces shall be fairly covered; and with this construction of boiler a smaller quantity of water will not answer that purpose. A certain body of water is indeed necessary to prevent sudden fluctuations in the pressure of steam; but in the majority of cases a few hundred gallons at most is quite enough for this purpose; and especially where means are employed for drying or superheating the steam, there will be neither sudden alterations in the pressure nor difficulty in respect of priming, even where only a small body of water is maintained in a boiler and where the water level or surface from which the steam rises is of but small area. Moreover it should not be forgotten that with all steam boilers the whole or nearly the whole of the fuel employed in raising steam from cold water at starting is lost when the boiler stops work at the end of the week, especially where the boiler has then to be blown out. To heat 20 tons of water from its ordinary temperature in the open air to 300° Fahr., the temperature corresponding to a steam pressure of 50 lbs. per square inch, will seldom take less than 15 cwts. of coal, in addition to that lost in heating the brickwork setting of the boiler.

On this account therefore it is desirable to work boilers with as small a quantity of water as will suffice for every necessary purpose.

The Cast Iron Boiler about to be described has been constructed with reference to the foregoing considerations. It was the object of the inventor, Mr. Joseph Harrison of Philadelphia, United States, to provide great strength against bursting, and to obtain also a large extent of heating surface in proportion to the weight and external dimensions of the boiler: it was important moreover to obtain perfect circulation for the water. The experience with this boiler for several years in America and for upwards of two years in London and Manchester, in one case with a boiler supplying steam to the extent of 200 indicated horse power, has proved that these objects, as well as other important advantages, have been secured.

The boiler is shown in Plates 19 to 23. Fig. 1, Plate 19, is a longitudinal section; Fig. 2, Plate 20, a front elevation; and Figs. 3 and 4, transverse sections. Figs. 5 and 6, Plates 21 and 22, are longitudinal and transverse sections to a larger scale.

The several parts of the boiler received different forms in the earlier experiments several years ago, but these led to the adoption of the present hollow cast iron spheres, connected by hollow necks, and secured together by bolts, as shown in the longitudinal sections, Figs. 1 and 5, Plates 19 and 21. Figs. 7, 8, and 9, Plate 23, are enlarged sections of one of the castings, which includes four spheres, each 8 inches external diameter, $\frac{3}{8}$ inch thick, and connected by necks of $3\frac{1}{8}$ inches opening. Each of these castings is called a "unit." Each "unit" of four spheres has eight openings, $3\frac{1}{8}$ inches internal diameter, the edges of which are faced up to a true surface, so as to bear fairly upon the corresponding faced surfaces of the adjoining units. Each joint has a shoulder and socket, as shown full size in the section, Fig. 10, Plate 23, so as to steady the units in their place. Steam-tight caps are provided to cover the external openings, as shown in Figs. 8 and 9; and the whole series of units, forming a vertical slab of rectangular or other shape, are held together by bolts of $1\frac{1}{4}$ inch diameter, passing inside the spheres and through the water or steam which they contain.

Each slab, whatever number of units it may be composed of, may be regarded as a separate vessel, throughout which the water or steam can circulate freely, both vertically and longitudinally. Any number of slabs may be placed side by side in the same fireplace; in the boiler here shown there are eight, as seen in the transverse sections, Figs. 3, 4, and 6, Plates 20 and 22. They are connected together by a feed-water pipe A at the bottom and by a steam pipe B at the top. The water level is usually maintained so that about two thirds of the whole number of spheres will be constantly filled with water, as shown in Figs. 5 and 6, and by the dotted line in Fig. 1; the remaining spheres forming a steam space. The full heat of the fire is prevented from coming upon the upper spheres which contain only steam, by small firebrick screens or cast iron plates C C, Figs. 5 and 6, which are placed loosely between the slabs, a little below the water level, so as to confine the direct action of the heat chiefly to the spheres filled with water. The upper spheres are at the same time enveloped in an atmosphere so hot as to ensure the steam being completely dried. The slabs are fixed with an inclination in the direction of their length, as shown in Figs. 1 and 5, sufficient to ensure the complete drainage of all the spheres when the boiler is blown out. This inclination serves at the same time to bring the largest body of water to where the action of the heat is most direct, and to provide the largest steam space over that part of the boiler where ebullition is probably the least active. The earlier experiments have shown that, although the units may be bolted together into slabs of a total length of even 20 feet, a length of 9 feet is preferable, since the strain upon the bolts in screwing up is correspondingly less: and as in the latter case there is no observable tendency to sag in the centre, the complete tightness of the joints is thereby secured.

The spheres weigh each about 22½ lbs., a unit of four spheres weighing rather more than ¾ cwt. Hence there are very nearly one hundred spheres to the ton; and it has been the habit thus far to rate these boilers by their weight, as a 4 ton boiler, an 18 ton boiler, &c. The nominal horse power of the boiler may be generally taken as three times its weight in tons. Thus a 10 ton boiler may be rated as of 30 nominal horse power; and from experiments it appears that a boiler of this weight may be counted upon to evaporate 40 cubic feet of water per hour, corresponding to about 80 indicated horse power. Each sphere contains seven pints of water, a unit of four spheres containing 3½ gallons. The external surface of each sphere is rather more than 1¼ square feet, and the internal surface a little more than 1⅛ square feet. In round numbers it may therefore be said that each sphere presents a square foot of heating surface and contains a gallon of water; while a ton of one hundred spheres represents three nominal horse power, the proportion of weight to power being thus about the same as in Lancashire boilers of the ordinary type.

Although it cannot be said that cast iron is in itself a strong material for boilers, yet it will be seen that, in the form now described, it affords greater absolute strength against bursting than is possessed by any form of plate iron boiler at present in use. The units are cast upon green sand cores, so placed that they cannot alter their position in the flask by any force short of what would be sufficient to crush them to pieces. The thickness of metal in the spheres is therefore uniform throughout, as has been proved by breaking great numbers of units taken at random. In a unit of four spheres, each sphere having an internal diameter of 7¼ inches, the whole area of the plane in which a bursting pressure would act, taken through the eight openings of the four spheres, as in Fig. 8, Plate 23, is 220 square inches; while the least section of iron resisting this pressure in the same plane is 27½ square inches. The iron employed is an equal mixture of Glengarnock, Carnbroe, and scrap: a mixture selected for its free running quality, and much used for small machinery castings. Its tensile strength may be safely taken as 5½ tons per square inch. At this rate the bursting strength of the units would be 1540 lbs. or nearly three quarters of a ton per square inch internal pressure. The first experiments actually made to test the bursting strength of the units were made more than two years ago in Brussels for the Belgian Minister of Public Works. In this case a pressure of 98 atmospheres or 1440 lbs.

per square inch was applied. This was as high as the force pump employed could go, but the spheres were not burst.

A further series of experiments for the purpose of testing the bursting strength of the cast iron spheres have recently been made at the Gorton Foundry, Manchester. A high-pressure Schaeffer's gauge graduated to 1000 lbs. per inch was attached to one of the units or castings of four spheres, to which the caps had been accurately ground, and water pressure was then applied by means of a force pump. The pointer of the gauge passed the 1000 lbs. mark to an extent indicating from 1150 lbs. to 1200 lbs., but the spheres did not burst. The pressure gauge was then checked by comparison with a Bourdon gauge up to 500 lbs. per square inch, and found to agree within 10 lbs. By calculation from the weight applied to the force pump lever and the dimensions of the pump it was estimated that the total force applied, including the friction of the pump, was about 1470 lbs. per square inch. Another similar casting was afterwards tested in the same way with a similar result. The castings were subsequently broken with a sledge hammer, and showed a uniform thickness at all parts and a good quality of iron. A safety valve was then arranged for the purpose of ascertaining the bursting strength of the spheres; the seat of the valve was 1-4th square inch area, and the head of the valve 1¼ inch diameter, the valve being ground carefully to its seat. The spheres were burst at a pressure calculated at 1850 lbs. per square inch; but on comparing the safety valve with a pressure gauge it appeared that water must have worked its way over the ground seating of the valve, allowing the pressure to act upon a greater area than 1-4th square inch, and that the true pressure could hardly have been so much. The head of the valve was then reduced to a diameter of ⅞ inch, and the spheres were burst at a calculated pressure of 1650 lbs. per square inch; but it was still found that some water must have worked over the valve seating, and the experiments with the safety valve were not therefore altogether satisfactory, but there appeared no reason to doubt that the bursting pressure was not far short of 1500 lbs. per square inch. All these experiments were made upon castings having their covering caps ground carefully to them, and the bolts were only about 9 inches long between the caps covering the opposite openings of the units. When however a slab of say one hundred spheres is bolted together, the bolts being upwards of 9 feet in length become so far stretched by a strain considerably below the bursting pressure as to cause the joints to open everywhere and relieve the pressure. In this way every joint becomes a safety valve. This never occurs with any practicable steam pressure, but it did take place in many of the earlier experiments made to burst the spheres, although leakage seldom commenced until a strain of nearly or quite half a ton per square inch had been applied.

The above experiments were all made with new castings, and at the time they were made no other spheres could be had which had been more than twelve months in use; and the condition of these was clearly the same as when new. It would appear therefore that the boiler now described possesses the same degree of safety under a pressure of 230 lbs. per square inch as a 7 feet Lancashire boiler under a pressure of 50 lbs. If however one of the units of the cast iron boiler should burst, it could not do more than empty itself, and open one or more 3⅛ inch apertures into the units adjacent to it; whereas if an ordinary boiler, containing say 20 tons of highly heated water in one compartment, should burst, the consequences would be most disastrous. In some of the earlier boilers of the kind now described the setting was such that an excessive strain was brought upon one or more joints; and here, in order to prevent leakage, the bolts had to be tightened with great force, and in two or three cases castings forming a part of the boiler were thus cracked from one joint to another. The consequence was an escape of steam or water, but no further damage ensued. In one of these instances a unit thus cracked was worked continuously for three days, and it might perhaps have been worked for a still longer time; but it was thought prudent to replace it by a sound casting. No instance of a fracture has occurred in the cast iron boilers with the present mode of setting, and all the boilers of this kind yet erected are quite free from leaks at the joints.

The bolts securing the castings together have a strength much beyond even that at which the spheres would burst. They are under a certain initial strain before any pressure is raised in the spheres; but the amount of this initial strain is known and under control, for in screwing up the slabs a 27 inch wrench is employed, and the strength of but one man is applied to it. If however a great strain be put upon the bolts, the crushing strength of the castings is found to be greater than the tensile strength of the bolt. In a series of experiments made at the manufactory of these boilers by Mr. Luders a slab of units bolted together to a length of 9 feet was screwed up with great force; a wrench 10 feet long was employed and the force of three men applied. In every case the castings were compressed to the extent of 1-8th inch in a length of 9 feet, when the bolt commenced to stretch, and after elongating $1\frac{1}{4}$ inch it broke. This experiment was repeated twelve times with the same result, the castings remaining uninjured. The castings when laid loosely upon a brick pavement require a powerful overhead blow from a heavy sledge hammer to break them. They have also been heated in a forge to a bright cherry red colour, and then plunged in cold water, without cracking: though there is no doubt that the iron was seriously injured by this treatment, and it might have been expected that the spheres would break to pieces. Their endurance is to be referred to their form and to the tough quality of the metal from which they are cast; a sharp blow with the edge of a hammer indents the iron nearly the same as if it were boiler plate.

It might have been apprehended that the expansion of the castings, when in service in a boiler, would be such as to cause unequal strain upon the joints. No leakage however can be detected at any of the joints of a single slab of castings; and as each slab is supported chiefly at its lower corner, and all the slabs of a boiler are separate from one another, except at a single point at top and bottom where the steam and water connections are respectively made, it is found that the slabs are under no injurious strain. Moreover all the spheres have a considerable amount of elasticity under strain, which would assist in compensating for unequal expansion, did this exist. These conclusions as to the effect of expansion are derived from an experience of 2½ years with one of these boilers of 12 horse power at the chemical works of Messrs. Denton at Bow Common, London; two boilers, one of 50 horse power and the other of 12 horse power, at the engineering works of Messrs. Hetherington, Manchester; and a 12 horse power boiler at the manufactory of these boilers, Openshaw, Manchester. The two boilers at Messrs. Hetherington's are often worked, collectively, up to 200 indicated horse power; the first was erected at their works about eighteen months ago. The boilers of this construction were originally bolted up in slabs 25 feet long, where considerable power was required; but in such cases it is now preferred to employ two or three slabs, one behind the other, as shown in Fig. 1, Plate 19, each slab being 8 or 9 feet long. When this arrangement was first employed, the steam space of the back slab was connected by a pipe with that of the front slab, the steam being taken off to the engine from the front slab alone; and the steam pipes connecting the front and back slabs being made of cast iron, and of a form which did not allow of the unrestricted expansion of the slabs, some of the pipes consequently cracked; but they are now made of wrought iron and of a curved form, as shown in Figs. 5 and 6, Plates 21 and 22, so as to yield readily to a moderate strain.

The inventor of this boiler, Mr. Harrison, had from the first expected an entire freedom from corrosion of the spheres; and the experience thus far has borne out this anticipation. Cast iron is well known to endure much better than wrought iron under the action of flame, water, and other corrosive influences. In the case of gas retorts for instance, plate iron would be immediately burnt through; whereas, previous to the introduction of clay retorts, cast iron answered very well. The pipes for heating the blast of blast furnaces were originally made by Mr. Neilson of plate iron; but although the blast was then heated to only 350°, it immediately became necessary to resort to cast iron heating pipes. The superior durability of cast iron forge tuyeres, especially when made hollow and lined with water, is also well known. In the case of the present boiler many castings have been purposely removed and examined after being at work; but their weight has been found the same as when they went in, and the joints showed no degradation of their original surface.

The question which caused most apprehension in the first instance in connection with this boiler was the possibility of maintaining a clean surface within the spheres. The cast iron boiler may be said to belong to the class of water-tube boilers or those having small water cells. This class of boiler is about sixty years old, for one was fitted in Meux's brewery in London by Arthur Woolf in 1804; and in the same year a small screw steamboat was worked on the river Hudson by John C. Stevens of New York, the engine of which was made by Boulton and Watt, while the boiler had 81 water tubes, 1 inch diameter and 2 feet long. From the first however such boilers have generally failed on account of defective circulation and the difficulty of keeping the tubes free from internal deposit. Many attempts have been made to remove this difficulty. Circulating pumps have been employed in addition to the ordinary feed pump, to maintain a constant circulation of water through the tubes. The boilers of the first American steam fire-engines were thus constructed, and some time since a description of such a boiler was given in this Institution. Other forms of water-tube boilers have been made with different means for promoting a circulation of the water; but in all cases the whole of the inorganic matter contained in the feed water must remain in the boiler, unless it be blown out while working; and in the case of some salts held in solution by ordinary boiler water, these are inevitably and almost irremovably deposited upon some part of the internal surfaces. The boiler now described forms no exception to the general experience in this respect. The water with which Messrs. Hetherington's boilers and indeed most of those in Manchester are fed is such as to deposit a hard scale 1-8th inch thick after a few weeks' working. A tool had been contrived with steel scrapers so hinged that it might be entered through any of the openings in the spheres of the cast iron boiler and be then expanded out to the internal circumference of the spheres: by then working this tool within the sphere the scale would be removed so that it could afterwards be blown out.

It has unexpectedly turned out however that no occasion has arisen for the use of this scraping tool. The boiler was blown out regularly at the end of every week, and it was found that the supply of steam continued good without any use of this tool, and that none of the spheres became overheated or leaking. After ten months' work of the 50 horse power cast iron boiler at Messrs. Hetherington's, it was desired to increase the boiler power at their works; and as the boiler then in use there was formed of units having only two spheres each, it was replaced with a new boiler having four spheres in each unit, excepting the units employed for breaking joint, which had two spheres as before. On taking down the old boiler little or no scale was found in any of the spheres, two of which, in the same condition as when taken down, are now exhibited to the meeting. One taken from the 12 horse power boiler at the same works was broken by the writer and is also exhibited. This was purposely taken from near the bottom of the boiler, and it had worked constantly for eight months without any examination. It will be seen that the broken pieces, which are in the same condition as when the casting was taken out and broken, contain no scale. In taking down the old 50 horse power boiler however a lump rolled out from one of the spheres; and this, the only piece of the kind found, is also exhibited. It consists of scales seldom larger or thicker than a sixpence, loosely cohering together by a clayey deposit from the water; in the mass it is very friable, but the fragments of scale are themselves of the same obdurate sulphate of lime as that which hardens in nearly all other boilers in the same district; yet these scales have in every case separated from the iron before attaining a thickness greater than 1-16th inch. It cannot be because the boiler is of cast iron that it so readily sheds its scale; for Trevithick's boilers and the cast iron "elephant boilers" long ago made by Mr. Hall of Dartford enjoyed no immunity in this respect as compared with wrought iron boilers fed with the same kind of water. In the Lancashire district too, the cast iron pipes of the apparatus used for heating the feed water for boilers are subject to choking with scale in the same manner as if they were made of wrought iron; and in some cases they become completely choked and can be cleared only by a boring tool. The fact that the spheres of this boiler shed their scale is not to be referred therefore to their being made of cast iron. It might perhaps be imagined that the water is occasionally driven from the internal surfaces, and that the consequent expansion of the spheres and their subsequent contraction on the return of the water would account for the scale becoming loosened and broken off. But the spheres show no evidence, as in this case they might be expected to do, of any irregular action of the fire; and moreover those of the spheres which are placed far behind, where the action of the heat is moderated, are equally free from scale. It appears to be more probable that, as the spheres expand at all parts, and in cooling contract equally at the same parts, the scale is detached and crushed in this process of contraction. If this conjecture be correct, the unexpected separation of the scale may be attributed to the form and dimensions of the spheres themselves.

Whatever explanation may be offered, it is certain that with foul water and such as gives much trouble in other boilers the scale breaks off freely into small pieces in this cast iron boiler; and this is perhaps one of its most valuable properties, although quite unforeseen. It would not be prudent to anticipate the result in the application of this boiler to marine purposes; but in all the land boilers of this construction it has been found that with blowing off once a week they may be worked for an indefinite length of time without any accumulation of scale. It will be seen how readily this boiler may be laid open for examination, and it was recently thought expedient to open the large boiler at Messrs. Hetherington's works for this purpose. A small quantity of loose and broken scale, not above a tablespoon full, was found in each of the units examined; but their internal surfaces, so far as they could be seen, were entirely clear.

The evaporative efficiency of the cast iron boiler depends, as in the case of all other boilers, upon the amount of heating surface exposed in proportion to the consumption of a given weight of fuel in a given time. The boiler by which Messrs. Hetherington's works are now driven supplies an amount of steam which a single Lancashire boiler, 7 feet diameter, 30 feet long, and weighing 14 tons, was found inadequate to produce. Both the original and the present boiler are in connection with a chimney 165 feet high, which affords an excellent draught. The original boiler had two flues, each 2½ feet diameter and enlarged at the fireplace to 3 feet. The area of the firebars was 36 square feet, and the total "run" of the heat was 90 feet in length before quitting the boiler. The cast iron boiler now in use has about 1800 spheres, weighing 18 tons, and presenting about 1600 square feet of surface in the water spheres and about 700 square feet in the steam spheres; the area of firegrate is 33 square feet. The usual quantity of water carried is 147 cubic feet or rather more than 4 tons, the quantity usually carried in the original Lancashire boiler being nearly 20 tons. The external dimensions of the present boiler are considerably less than those of the Lancashire boiler. Rather more than 3 cwts. of coal are required in the cast iron boiler for raising 50 lbs. steam from cold water, and the time occupied is about half an hour. In order to ascertain the exact evaporative efficiency of the boiler, it would be necessary to begin the observations when it was in full work, and to continue them uninterruptedly for a considerable time. As the boiler is now worked, the fires are lighted on Monday morning and let down on Saturday afternoon; but they are banked every day at breakfast time, at noon, and at night. The mass of brickwork which is thus alternately heated and cooled with the boiler is very great; and the quantity of heat that enters it, which is for the most part wasted on stopping, is correspondingly large. Except at the beginning of the week, the temperature of the water in the boiler on starting in the morning is at least 212°, while the feed water from the hot well is usually between 90° and 100°.

In February last the writer made a series of careful observations upon the working of this boiler, more especially to ascertain its evaporative efficiency. The coal was of good quality, from the Oldham Pits, and was carefully weighed; and the feed water was made to pass through one of Worthington's water meters on its way to the boiler. The indications of the meter were ascertained to be accurate, by its registration of 147¾ cubic feet in filling the boiler up to a point known to correspond exactly with that quantity. In the first day's trial, between 5.40 a.m. and 12.55 noon, with an interval for breakfast, the whole consumption of coal was 38 cwts. and of water 442·7 cubic feet. If this quantity of water evaporated were to be divided by the gross consumption of coal, the result would be only 6·48 lbs. of water evaporated per lb. of coal: but in heating the boiler and its contents to the working point, and in the loss at breakfast time, the consumption of coal was such that 24 cwts. were burnt for evaporating the first 200 cubic feet of water; while the remaining 14 cwts. held out for the time during which 242·7 cubic feet of water were evaporated. Allowing for the lowering of the fires at the hour for stopping work, the quantity of coal actually expended in evaporating the 242·7 cubic feet of water may be taken as 16 cwts., corresponding to an evaporation of 8·43 lbs. of water per lb. of coal. Towards the end of the day's trial, in a period of 1 hour 40 minutes, 8 cwts. of coal were burnt and 142·7 cubic feet of water evaporated: but as this would correspond to an evaporation of 9·91 lbs. of water per lb. of coal, a portion of the water must have been evaporated at the expense of the heat already in the water and in the boiler and its brickwork setting. That this was the case is shown by the fact that in the last 50 minutes of the trial only 2 cwts. of coal were burnt while 80 cubic feet of water were evaporated; a proportion which, were the total evaporation due to the quantity of coal actually burnt within the same period of time, would have corresponded to an evaporation of 22 lbs. of water per lb. of coal, which would of course have been impossible. In making these observations there was always the uncertainty attending the quantity of coal that should be assigned to heating the boiler, and its contents and setting, up to the working temperature, and the quantity that was to be set down to evaporation alone.

In the second day's trial, starting on Monday morning with water at about 45° temperature, 5 cwts. of coal was consumed in raising steam to the working pressure, the time occupied being half an hour.

Including the coal burnt in raising steam, 2 tons 18 cwts. were consumed during the day, and 657 cubic feet of water were evaporated, corresponding to an evaporation of 6·30 lbs. of water per lb. of coal. But as a greater quantity of heat was manifestly left in the boiler and brickwork on stopping at night than when work was commenced in the morning, and as there was a waste of heat during the breakfast and dinner hours, not more than 2½ tons of coal at most can be fairly charged to the water evaporated, and this is probably in excess of the actual quantity. This corresponds to 7·31 lbs. of water evaporated per lb. of coal. The evaporation from noon until the hour of stopping at night averaged 7·56 lbs. of water per lb. of coal, while for the last four hours of the experiment the apparent rate of evaporation was 8·71 lbs.

In the third day's trial, steam having been kept in the boiler over night, the consumption of coal from 6.0 a.m. till 2.30 p.m. was 2 tons 6 cwts., which included the loss during the breakfast and dinner hours, and the evaporation was 519 cubic feet, corresponding to 6·27 lbs. of water evaporated per lb. of coal.

In a whole week of 57½ hours an average of 77 cubic feet was evaporated per hour, the maximum evaporation being about 82 cubic feet per hour, and the average consumption of coal was 6·25 cwts. per hour. This corresponds to 6·85 lbs. of water per lb. of coal; but, allowing for the sources of loss already pointed out, nearly 8 lbs. may be taken as the effective rate of evaporation. The temperature of the escaping gases, as indicated by Gauntlett's pyrometer, was about 600° on the average, the steam of 50 lbs. pressure showing the normal temperature of about 300° by a thermometer inserted for the purpose. The average rate of combustion was 21 lbs. of coal per square foot of firegrate per hour. When the fires were not driven so hard the rate of evaporation per lb. of coal was increased, and the temperature of the escaping gases fell to 525°. The flame penetrated freely between the spheres for a distance of 8 or 10 feet from the bridge, and three fourths of the whole evaporation probably took place within this distance. The spheres in the slabs at the back of the boiler were generally covered with a light coating of soot, which was swept off every week, all the spheres being within easy reach for this purpose; soot never formed however upon the spheres near the fire. The water level was very steadily maintained within a small range of oscillation; and as the feed water entered the boiler at the back, there could be no doubt, when it stood at its proper height in the glass gauge in front, that its level was properly maintained throughout the whole length of the boiler. A small cock tapped into one of the steam spheres a short distance above the water level showed damp steam, indicating a vigorous circulation of the water below; but in the engine room the steam blown from the cylinder cock was quite dry, showing the value of the superheating surface formed by the upper or steam spheres of the boiler.

In reference to the mode of making the castings of the boiler and forming the joints, the system pursued in the foundry is such that, with green sand cores, the units are moulded with about the rapidity and economy of plate moulding. The cores are well rammed on the eight prints upon which they rest in the sand, and there is no chance of their being displaced in pouring the metal or otherwise, except by a force sufficient to break them in pieces. The two halves of the moulding boxes are drawn apart in such a manner as to prevent any chance of breaking down the sand, and little or no sleeking is required. Each casting is critically inspected; but as the moulders are not paid for imperfect castings, very few are made.

The joints are faced up by special and powerful machinery. The spheres are 9 inches from centre to centre in the same unit, and the facing machines not only preserve that distance exactly between the openings on the same side of each unit, but also face the joints on the opposite sides of the unit to the precise gauge of 8¾ inches apart. Each machine has two headstocks, with eight spindles and rose cutters in each headstock; and the castings being securely held in a clamp are faced in pairs, a roughing cut being taken on the eight joints of one casting, while a finishing cut is going on upon the joints of the other. Twenty-five tons of castings pass under the roughing cutters before they require grinding; and

100 tons of units are completely faced by the finishing cutters before these require to be re-ground. By a special adjustment the finishing cutters may be set up in their spindles to the one-thousandth part of an inch, whenever, from the dulling of the cutting edges, the distance between the opposite joints of the units is found to exceed the length of the standard gauge by that quantity.

Out of a number of castings, any two exactly correspond, and when placed together the bearing surface at each joint is 3-16ths inch wide all round, and it is finished with a truth not inferior to that of a good slide-valve face. If a sheet of oiled paper be placed upon a smooth board and two units be placed upon it, one above the other, they may be filled with water without any perceptible leakage at the joints even after the lapse of a week.

In conclusion it is considered by the writer that the boiler now described possesses several important advantages. It is believed to be absolutely secure from explosion, and, so far as experience has gone, free from any liability to choke with scale. It is durable, easily taken apart and put together, and may be erected in almost any form adapted to the space in which it is to be placed. The parts are very portable, and may be taken through any opening where a boy can pass. Any part of the boiler may be readily renewed if necessary; and an existing boiler may at any time be readily enlarged, and that to an indefinite extent, by adding to the number of slabs, either at the sides or at the back. The economy of the boiler in first cost is obvious; and with proper proportions between the firegrate and the heating surface, as high an evaporative efficiency may be obtained as with most other constructions of boilers. The quantity of water contained in the boiler being comparatively small, steam may be raised with a small quantity of fuel and in a short space of time. Water may be left standing in the boiler for almost any length of time without injury. Every part of the boiler is at all times under ready observation without disturbing the connections; and the outsides of the spheres may be easily swept. The setting of the boiler is such that the steam may be dried to any extent desired in the spheres themselves, without any other provision for superheating. It is thought that this boiler especially meets the present increasing tendency to use high pressure steam, and that the description now given will therefore prove interesting to this Institution.

Mr. Colburn exhibited a set of spheres from the boiler, forming one complete slab, and also specimens of the steam and feed connections at top and bottom of the boiler, together with one of the spheres that had been broken open after eight months' constant work, to show the state of the interior surface and its complete freedom from corrosion or scale. He showed also specimens of the thin small scales blown out from the boiler, which was all the deposit there was to be found; and of the thick hard deposit chipped off from the interior of an ordinary Lancashire boiler using the same water.

The Chairman had seen the new boiler at work in Manchester, and considered it an important step towards the use of steam at a higher pressure than could at present be adopted. It was much more simple in construction than would at first sight appear; and with the facilities now possessed for multiplying parts of the same size and shape, he did not see any reason why it should not be put together easily and at a very small cost. He enquired what was the temperature of the waste heat passing off from the new boiler into the chimney, as that was an important criterion of the economy of a boiler.

Mr. Colburn had not had an opportunity of ascertaining the temperature of the waste heat from this boiler, but by increasing the length of it the heat at the chimney end could be reduced as low as desired. At Messrs. Hetherington's works in Manchester there were originally two ordinary Lancashire boilers, but when the new boiler was added only one of these was worked with it; the waste heat from both however passed into the same chimney, so that there was no opportunity of trying the temperature from the new boiler alone. The boiler at those works was in the first instance longer, but was afterwards shortened by the removal of some of the spheres at the further end. The water was left in the boiler during the night, and in the morning was still at a temperature of 212° Fahr., owing to the heat retained in the mass of brickwork surrounding the boiler; and from this point steam was got up in 10 or 12 minutes to a pressure of 50 lbs. per square inch above the atmosphere. There was great convenience for readily inspecting the boiler by means of the manhole doors, by which access was obtained at once to the whole boiler, with a clear sight through the entire length, and a man could get in and sweep the whole of the spheres clean without any difficulty at all.

As regarded the freedom of cast iron from any tendency to corrosion, when used as the material for steam boilers or for other purposes where it was exposed to a high temperature, he was informed by Mr. Jaffrey of Hartlepool that he had employed cast iron for superheaters with success, and four cast iron superheaters fitted on board steam colliers showed no sign of corrosion when examined in October last, after four years of almost constant work; the pipes when cleaned looked almost like new castings, almost as clean as when first put in.

Mr. G. A. **Everitt** thought the new boiler would be very useful in connection with puddling or heating furnaces, where the waste heat from the furnace was made use of for generating steam; it appeared very suitable for such applications on account of its safety and the small space it occupied, and he enquired whether it had been employed for that purpose.

Mr. T. L. **Luders** replied that he was now about to put up one of the boilers to be heated by the waste heat from three puddling furnaces: there were eight sections of spheres in the boiler, and the heat from the furnaces was made to circulate completely through the set of spheres in each section by means of firebrick partitions, making the passage to the chimney the longest possible. The boiler was carried entirely upon a pair of cast iron columns in front and the brickwork upon which it rested at the back, independent of the brickwork of the furnaces; so that the latter could be pulled down for repairs without disturbing the boiler, while the boiler also was completely accessible at all times without requiring any part of the brickwork of the furnaces to be removed. The boiler had thus the important advantage for such an application that it could be placed over the furnaces without occupying any of the room of the forge or hindering the repairs of the furnaces. By means of suitable dampers the amount of heat allowed to pass through the boiler could be regulated as desired, according to the generation of steam required; and the heat from any one of the furnaces could be conveyed away direct into the chimney, without passing at all through the boiler, if only a smaller quantity of steam were wanted to be raised.

In the earlier boilers that he had made, the spheres were set at an inclination of about 15°, but in the most recent ones they were placed at 45°, which was found to answer the best, because it gave a complete drainage of every sphere in the boiler into the bottom blow-off pipe; while the point of taking off the steam being the highest in the boiler was the furthest from the water line. Near the level of the water line the steam would of course be damp from contact with the water; but the surface of the spheres above the water line being exposed to a high temperature, say 650° Fahr., the steam became moderately superheated to a temperature due to that exposure before passing off from the top of the boiler, and it was then found hot enough to continue dry after passing through 40 feet of unprotected pipe to a low pressure engine worked by it.

The **Chairman** enquired what was the cost per horse power of the new boiler.

Mr. T. L. **Luders** replied that the cost of the boiler was £15 per ton at the works in Manchester, and the power was reckoned at about 3 horse power per ton, making the cost per horse power about £5. In reference to the temperature of the waste heat escaping from the boiler, he had found the waste heat from an ordinary Lancashire boiler doing rather less work than the new boiler was from 580° to

600°: while the waste heat from the new boiler was from 500° to 600°. The extent of variation in the latter case was accounted for by the quantity of coal consumed per square foot of grate per hour, amounting to 21 lbs. of coal; and it was evident that as the consumption of coal was increased, and the rapidity of the draught also increased by opening the chimney damper in order to burn the larger quantity of coal, the heat escaping into the chimney must also be proportionately increased. The Lancashire boiler experimented upon was one with a moderate draught, but having a larger firegrate area and burning its fuel much slower than 21 lbs. per square foot of grate per hour. That would give a much higher evaporative efficiency, and the temperature of the waste heat escaping to the chimney would be lower, owing to the draught being less keen and the heat being more fully taken up by the boiler.

Mr. C. W. Siemens remarked that certainly the new form of boiler was emphatically a strong form, inasmuch as a sphere of 1 foot diameter had as much strength to resist internal pressure as a pipe of half that diameter, the thickness of metal being the same. Moreover the spherical form was a very good form in cast iron he thought for a boiler, because it yielded to expansion equally in all directions: cast iron readily gave way when exposed to unequal heat, and in ordinary plate boilers the wrought iron often gave way in consequence of unequal expansion in different parts. But he did not expect that the new boiler would give way by any part being overheated in comparison with the rest, because every portion of a hollow sphere could yield freely to local expansion by heat. He had at various times used cast iron heated to a high temperature, and had found that, to make it stand, the question of expansion had above all things to be attended to. The heating surface in the boiler appeared likely to be highly efficient, because the flame was continually broken in its passage over the interrupted surface presented by the balls, instead of passing through a long plain internal tube in a continuous unbroken current, as in an ordinary boiler, where the interior mass of the flame came comparatively little in contact with the boiler surface. He therefore hoped the new boiler would receive a fair trial at the hands of those using steam boilers. The several balls composing the boiler must require to fit together with very great nicety in order to prevent leakage at the joints, and he enquired whether they had ever been found to leak at the joints; and whether they were not found to give way at the joints after working for a considerable time, in consequence of the alternate heating and cooling, since cast iron by being heated and cooled very often was known to become permanently enlarged.

Mr. T. L. **Luders** replied that there had not at present been a very long experience with the new boiler of which to speak, but so far as the tightness of the joints had hitherto been tested by time their durability had been surprising, as they had never shown the slightest sign of a leak. Very much depended in practice upon the facing of the joints being truly accurate machine work, and this was ensured by the mode of facing the two sets of cutters of the machine in which the joints were faced simultaneously on opposite sides: while the cutters were all revolving, firmly wedged in their holders in their permanent working position, but of soft steel not yet hardened, a facing tool sharpened at both edges and made by a standard gauge to correspond to the exact distance between the joints was passed transversely across the machine, grinding the cutters to the exact length required for facing the joints accurately to the proper length. The joints then fitted together perfectly without the slightest force being used, and when the bolt was passed through to hold them together they were quite steam-tight under any pressure of steam at which the boiler would be worked. There were 1800 balls in the last boiler made for Messrs. Hetherington's works, and not a single leakage had been detected in all that number. The result of two years' experience with the boilers at Messrs. Sellers' machine works in Philadelphia was that there had been no leakage; while at the same time the boilers had been so economical that more than 100 tons of the ball castings for new boilers had been ordered from England for works at the same place, and would be put up in the place of good boilers at present in use there. The new boilers had now worked in America for eighteen months with only once being opened at the end of eight months for the purpose of clearing the balls if that should be necessary, and then only a little scale and mud was raked out of the bottom row of balls; and during the ten months that had elapsed since that time they had not been opened at all. The experience in all cases had been the same as to the absence of scale or deposit, even after a long time of working.

With regard to the manner in which the new boilers stood the test of rust, one of them had been exposed for four years to the most severe test for rust that was likely to be met with. The boiler was 70 feet long and 1 foot high, in a greenhouse, where it was fired during only about three months in each year, and the remaining time it was allowed to stand full of water, which was no doubt the severest test it could be put to for rust. With plate boilers under such circumstances the plates were generally found to rust very rapidly. But this had not been the case with the new boiler: although the joints had been made four years they still continued perfectly water-tight, notwithstanding the fact that at the time the boiler was made there was no machinery for facing the balls, and the joints were merely planed and ground up with emery. The present machine-made joints were all found to remain perfectly tight.

The reason for setting the boiler in an inclined position instead of level, independent of the advantage of the balls emptying themselves completely when set inclined, was the fact that, in consequence of the difference of temperature between the water space and the steam space at the time of raising steam from cold water, the boiler could not be used if it were brought down level. For it was found by experiment that when the lines of balls were set horizontal a conflict resulted at the water line between the parts above and those below, in consequence of the difference of temperature, the cooler portions below the water line pulling against the more expanded parts above; and the strain produced would so rack the joints as to render the boiler a failure. This conflict disappeared however as soon as the lines of balls were set at the inclination of 45° that had now been adopted, as there was then no sudden change from hot to cool between any two adjacent lines of balls; and though all the tie bolts crossed the water line at different portions of their length, and thereby became unequally expanded by the hot steam space, yet the change was gradual from one bolt to the next, and no two adjacent bolts pulled against each other; and the expansion of the whole boiler thus took place without throwing a strain upon any part.

The feed pipe was connected to the bottom corner of the boiler in this inclined position, and the steam pipe was taken off from the top corner with a long bend, in order to allow perfect freedom for the expansion of the boiler, the effect of which would be all concentrated at that point. In the first boilers the steam connecting pipe was a cast iron transverse pipe with straight branches on the underside, to which the sections of the boiler were directly attached, forming a rigid connection at each section. But it was then found that the several connections in this case were so difficult to make in the first instance, from the difficulty of setting all the sections of the boiler in their places with sufficient accuracy, and when set the irregular expansion of the different sections was so apparent, from the unequal heat of the fire at different parts before the steam was fully up, that there was a pushing and pulling action at the connecting pipe which gave a great deal of trouble by breaking the castings, the pipe being stronger than the castings. This was however quite obviated by the present curved wrought iron pipes, forming the connections from the castings to the steam pipe, as seen in the specimen exhibited; these were screwed into sockets in every alternate casting, and allowed perfect freedom for the expansion of any section of the boiler, independent of the rest, so that there was now not the slightest trouble, nor any strain that could produce leakage at any of the joints.

The inclination of the balls at 45° gave the greatest length of water line, since the water line was then the diagonal of a square. It also allowed the steam to escape with great readiness from the water, as fast as it was generated, passing off without meeting or obstructing the water that was rushing in through another opening to take its place; and in consequence of this advantage the water level seldom oscillated more than $\frac{1}{8}$ inch: indeed that amount of variation in level was considered a great disturbance in the boiler.

Mr. F. W. **Webb** enquired whether the joints of the balls were put together simply metal and metal, or whether any red lead or oil was used for making them.

Mr. T. L. **Luders** replied that the joints were put together metal and metal, as in the specimens exhibited, just as they were left faced by the cutters of the machine, without any subsequent grinding, and without any oil or red lead or any other material in the joint. The cutting machine was made wide enough to take in one of the four-ball castings of the boiler, having four pairs of the revolving cutters, so as to cut all the four joints on each side of the casting simultaneously. The time occupied by the operation was about 8 minutes for each casting, from the time of putting the rough casting into the machine with the cutters drawn back, until it came out with all the eight joints finished ready for being bolted together at once in a boiler without any further preparation of the surface of the joints. The revolving cutters were advanced by a pair of eccentrics having $\frac{5}{8}$ inch throw, and were fed up by hand at first to bring them up to the surface of the casting, after which the self-acting feed motion of the machine was put in operation. The cutters came in contact with the metal when the eccentrics were at half stroke, having the quickest motion for advancing the cutters; and the forward motion then gradually diminished until the full throw was reached, at which time the speed of the revolving cutters was also diminished, so that at the last the tools gave nothing but a scraping finish to the face of the metal at a slow speed.

Mr. C. F. **Beyer** remarked that the new boiler was composed of a great number of separate parts put together, and at first sight it would appear that there must be considerable difficulty in making so great a number of pieces go together with sufficient accuracy to prevent leakage at the joints. He had however seen the machinery that was used for facing the joints, and thought it admirably adapted for the purpose; the accuracy with which it did the work was certainly very great, and there appeared no reason why the joints shaped by that machinery should not be water-tight and steam-tight under all pressures at which the boiler would work. The construction and working of the machinery were moreover such that the shaping of all the joints in the several castings of a boiler would form but a small item in the total cost of the boiler.

Mr. E. **Reynolds** enquired what became of the scale that was formed in the boiler during the week's work: whether it remained in the boiler until blown out at the end of the week, or whether any of it got carried over with the steam into the engine. He knew a pair of 50 inch cylinder engines upon the pistons of which an accumulation of from $\frac{1}{2}$ inch to $\frac{3}{4}$ inch thickness of scale was frequently found.

Mr. T. L. **Luders** replied that the boiler was not blown out at all except after working hours at the end of each week. From the result of observation he supposed that all the scale formed during the week's work became deposited on the surfaces of the balls in a layer about as thin as an eggshell, just in the same manner as on the surfaces of an ordinary plate boiler, so that the whole of the inside of the boiler became coated throughout the water space with a thin scale. In blowing out the boiler at the end of the week, the brickwork having been maintained during the week at a temperature of about 600° on the inside, it was only allowed to cool till the red heat had gone out of the bricks in the bridge wall, and then the boiler was blown out. But as there was still a temperature of as much as 500° in the brickwork, the whole mass of the empty boiler became very hot, and the scale either became altogether detached then by the expansion of the metal, or else the loosening of the scale was completed subsequently he presumed, when the boiler became cold, the contraction of the balls in cooling having the effect of crushing down the thin and friable scale in all directions and causing it to shell off from the metal in small pieces, or at least to become completely loosened from the metal, so that when the water was next put into the boiler it could get behind the scale and throw it off. The loose scale would then lie in small pieces at the bottom of the balls until the end of the week; and the scale formed in one week was therefore he imagined blown out at the end of the week following. The constant repetition of this process was he thought the reason of the balls being kept quite clear of scale. As to any scale being found in the steam pipes or cylinder of the engine, such an occurrence had never been met with in the working of any of the new boilers; but he thought it probable that, if the boiler were worked too long without blowing out, the balls would become choked with mud. He had however known every one of these boilers that had been put up at present, and had never found any incrustation larger than the small pieces of scale now exhibited, scarcely thicker than eggshells. This specimen was only collected by letting the water run out of the boiler slowly, and then opening the lowest ball and collecting the pieces of scale from it by hand, so that there was no doubt that was a fair sample of the weekly production of the boiler. This scale presented a great contrast to the other specimen exhibited of the scale obtained from an ordinary Lancashire boiler working with the same water, which was the usual description of scale found in all ordinary plate boilers, about $\frac{1}{8}$ inch thick and requiring to be broken from the inside of the boiler by blows of a hammer.

Mr. J. M. Hetherington said they had now had the new boiler in use at their works in Manchester for the last eighteen months, during which time they had made many experiments to test it in a variety of ways with most satisfactory results. The joints of the balls had been found entirely satisfactory, for he did not know of a single instance in which the joints in a good casting had given way. The castings as they came from the machine that had been described had all the joints faced so perfectly true that to put any cement or tallow or oil on them appeared to make them worse than the clean surface of metal to metal; and they remained completely steam-tight and water-tight under the expansion and contraction of the boiler. At the time of putting up the boiler at their works, when all the sections were screwed up and fixed in their places and the fire first lighted, he believed there was not a single leaking joint in the whole boiler.

The temperature of the waste heat escaping into the chimney from the new boiler he believed to be about the same as from an ordinary Lancashire boiler, between 500° and 600° Fahr.; but in the new boiler the whole of the heating surface being in such close proximity to the fire was more efficient than in ordinary boilers, where the further end of the boiler was sometimes as much as 90 feet distant from the fire, so that much of the surface could receive but little heat. The draught was much keener in the new boiler than in an ordinary one, and they had had some difficulty at first in so far checking it as to burn only the same amount of coal per square foot of grate as in ordinary boilers; but this difficulty had now been overcome. No doubt a reduction in the temperature of the waste heat would be advantageous, and it could be obtained by increasing the area of firegrate, so as to burn the coal more slowly and thereby give time for a little more of the heat from the fire to be retained by the boiler.

The practical result obtained with the new boiler at their works had been that it had effected a saving of 20 per cent. on the total cost of coal for raising steam: and in consequence of the capacity of the boiler for generating a high pressure of steam with perfect safety, they were now about to make use of steam of 100 lbs. per square inch pressure, or 120 lbs. in the boiler, by adding a high pressure cylinder to exhaust into the cylinder of their present condensing engine; and they intended to adhere to the cast iron boiler for the future, in place of the ordinary wrought iron boilers.

Mr. I. **Smith** enquired whether the water used in the boilers at Manchester contained sulphate of lime or carbonate of lime. He could understand sulphate of lime being deposited as a scale in the new boilers and being blown out at the end of the week, as had been described: but in the neighbourhood of Birmingham the water contained besides sulphate of lime a large quantity of carbonate of lime, which was deposited in boilers in the form of mud, and where the firing was below the boiler frequently caused damage to the plates by overheating. Hence if this water were used in the new boiler, unless there were a daily blowing out of the boiler, he thought great damage would result to the lower line of balls, as there appeared no reason why the new boiler should be exempt from the same accumulation of mud which took place in ordinary boilers using such water.

Mr. T. L. **Luders** replied that he had not any analysis of the water that had been used in the new boilers, and did not know what compound of lime it contained: the specimens of deposit now exhibited had the appearance of sulphate of lime, but he could not tell what would be the effect on the boiler if any deposit were ever formed that was elastic enough and sufficiently firmly fixed not to be cracked off the metal by the contraction of the balls in cooling. The expanding scraping tool described in the paper had been constructed to scrape out the scale in such cases if they ever arose; but no instance of the kind had yet been met with in the working of the new boilers, but in every case the result had been the same as regarded the absence of deposit, in America, in London, and also in Manchester; and he therefore thought there was reason to hope it would be the same in a great many other cases. In Philadelphia one of the boilers had now been working regularly for nearly two years, during which time it had only been opened once; and another boiler there was not opened for a period of eight months, and at the end of that time the whole collection of deposit that was left from the weekly blowing out was cleared away in a few hours by simply scraping out the lower line of balls with the tool provided for the purpose. The broken casting that was exhibited from the boiler in Manchester had never been opened until broken by the hammer after eight months' constant work: and the interior surface was exactly in the same state as when broken open, showing complete freedom from scale in all parts, though the boiler had been as much exposed to the liability of forming scale as any boiler was ever likely to be.

The **Chairman** proposed a vote of thanks to Mr. Colburn for his paper, which was passed.

The following paper was then read:—

ON THE DISTRIBUTION OF WEIGHT ON THE AXLES OF LOCOMOTIVES.

BY MR. JOHN ROBINSON, OF MANCHESTER.

Amongst the causes affecting the steadiness of locomotive engines in motion, and thereby also the general steadiness of trains on railways, the Distribution of Weight upon the various Axles, it is believed, has not received the amount of consideration which the subject deserves. There are numerous circumstances which must necessarily be taken into consideration for determining the position of the axles of an engine relatively to its general mass. The most important object is to obtain sufficient weight upon the driving wheels, whether single or coupled, for giving the amount of adhesion necessary to draw the load and ascend the gradients for which the engine is to be adapted: and another consideration of great importance in fixing the position of the axles is the number and sharpness of the curves on the road along which the engine has to pass. These two conditions naturally influence the distance between the several axles of the engine, especially the extreme ones, the distance between which is technically called the "wheel base."

These two main conditions, of the weight on the driving wheels and the nature of the curves on the line, being fixed, the question arises how best to distribute the weight of the engine on its axles. Some idea of the difficulties surrounding the solution of this question may be obtained by a glance at the accompanying diagrams, Figs. 1 to 15, Plates 24 to 28, which represent some of the multitudinous arrangements that have been adopted in order to meet the different requirements of railway companies. Locomotives in general may be divided for the present purpose into the fifteen classes illustrated by the diagrams, each of which it will be seen presents different obstacles to obtaining a proper distribution of weight upon the axles. The figures given as the weights at the several axles are taken with an ordinary working quantity of water and fuel in the boiler and firebox, and in the tank engines with the tanks fully loaded.

Fig. 1, Plate 24. Four-wheeled engines having Inside cylinders are generally used for mineral and coal lines, and for forming trains at stations. It will be seen by the diagram that a very large amount of weight here comes upon the hind axle, in consequence of the overhanging firebox; and this can only be alleviated by making the boiler unusually long in proportion to the firegrate and flue area, as shown by the dotted lines. The actual weights upon the axles of such an engine in working order, with cylinders 14 ins. diameter by 20 ins. stroke and wheels 3 ft. 9 ins. diameter, have been ascertained by the weighing machine to be

Leading axle	6·00	tons
Hind axle	12·50	„
Total adhesion weight . .	18·50	„

And with the longer boiler shown by the dotted lines the weights are

Leading axle	7·38	tons
Hind axle	11·80	„
Total adhesion weight . .	19·18	„

The weight required for maximum adhesion in this engine is 18·49 tons; that is the weight required for making use of the maximum power of the engine, under the most favourable circumstances when the adhesion friction is at its maximum amount of 1-5th of the load, and the mean effective steam pressure in the cylinders throughout the stroke being taken at 95 lbs. per square inch in starting the train.

Fig. 2, Plate 24. The unequal distribution of weight upon the axles of inside-cylinder four-wheeled engines, as shown in Fig. 1, may to some extent be avoided by placing the cylinders outside the frames, as in Fig. 2; for in this case the increased weight forward of the cylinders and their attachments, and the possibility of getting the straight driving axle much nearer to the firebox than a crank axle could be placed, tend more nearly to equalise the weight upon the two axles. On the other hand a less substantial engine is thus obtained, especially where coupled; since the coupling rod passing inside the connecting rod and the slide bars renders it difficult to secure a good attachment to the frames. The actual weights ascertained upon the axles of such an engine in working order, with cylinders 15 ins. diameter by 24 ins. stroke and wheels 4 ft. 6 ins. diameter, have been

Leading axle	10·00 tons
Hind axle	11·25 „
Total adhesion weight . .	21·25 „

the weight required for adhesion being 21·25 tons.

In Four-wheeled Tank engines, in which the supply of water and fuel is carried by the engine itself, by arranging the position of the water tank so as to keep its own weight, as well as that of the water it contains, well forward, the leading axle may be made to bear a larger proportion of the additional weight than the hind axle, whether the cylinders be placed inside or outside the frames. This is however counterbalanced by the necessity for lengthening the footplate and fencing it at the back, for the purpose of carrying the fuel, thereby increasing the weight overhanging the hind axle. The actual weights obtained in such an engine, with inside cylinders 13 ins. diameter by 18 ins. stroke and wheels 3 ft. 9 ins. diameter coupled, have been

Leading axle	7·45 tons
Hind axle	14·95 „
Total adhesion weight . .	22·40 „

the weight required for adhesion being 14·37 tons.

Fig. 3, Plate 24, and Fig. 4, Plate 25. The next class of engine is that which has hitherto been considered the ordinary type of Passenger engine, having six wheels all uncoupled, the middle or driving axle being placed under the cylindrical part of the boiler in front of the firebox, the leading axle behind the cylinders, and the hind axle behind the firebox. In arranging an engine of this description, it is usually sought to have the greatest weight upon the middle axle, then a less weight upon the leading, and a still less weight upon the hind axle; but to have these weights not so disproportionate as that it shall be impossible to vary the weight upon the middle axle within a moderate range by a corresponding adjustment of that upon the leading axle. In this respect the inside-cylinder arrangement presents an advantage over that with outside cylinders, since the leading axle in inside-cylinder engines can be placed much nearer to the smokebox and the weight upon it thereby diminished, on account of the cylinders not interfering with the leading wheels as in outside-cylinder engines. The connecting rod also is then capable of being made longer, in consequence of the increased distance from the smokebox at which the middle axle may be placed without throwing too much weight upon the leading axle, which in engines with short boilers is often a matter of considerable importance. It may be remarked that the arrangement of uncoupled engines with all the axles under the cylindrical part of the boiler is now almost discarded, at least in this country; since they are found to be so unsteady, in consequence of the overhanging weight of the firebox, that high speeds can not safely be accomplished with them.

Fig. 3, Plate 24, shows a good distribution of the weight in an Inside-cylinder Passenger engine, having cylinders 15 ins. diameter by 20 ins. stroke, middle wheels 5 ft. 6 ins. diameter, and leading and hind wheels 3 ft. 6 ins. diameter; the total weight being 23·06 tons, distributed as follows:—

Leading axle	8·16 tons	
Middle axle		10·10 tons
Hind axle	4·80 ,,	
Total adhesion weight . .		10·10 ,,

the weight required for adhesion being 14·48 tons.

Fig. 4, Plate 25, is an example of a favourable distribution in an Outside-cylinder Passenger engine, the "Lady of the Lake" of the London and North Western Railway, shown at the International Exhibition of 1862. With cylinders 16 ins. diameter by 24 ins. stroke, middle wheels 7 ft. 7½ ins. diameter, leading and hind wheels 3 ft. 8 ins. diameter, the distribution of the weight is

Leading axle	9·40 tons	
Middle axle		11·50 tons
Hind axle	6·10 „	
Total adhesion weight		11·50 „

the weight required for adhesion being 14·24 tons.

Fig. 5, Plate 25. The construction of uncoupled engines with tanks is not of very frequent occurrence. As however many such engines were made formerly, the distribution of one is given with the tank placed under the footplate behind the firebox; inside cylinders 15 ins. diameter by 20 ins. stroke, middle wheels 5 ft. 6 ins. diameter, leading and hind wheels 3 ft. 6 ins. diameter. The distribution was

Leading axle	7·35 tons	
Middle axle		10·25 tons
Hind axle	6·95 „	
Total adhesion weight		10·25 „

the weight required for adhesion being 14·48 tons. The placing of a tank underneath the cylindrical portion of the boiler in an outside-cylinder uncoupled engine simply tends to increase the weight upon the leading axle, already too heavily loaded, and has not been extensively adopted within the range of the writer's observation.

During the past few years there has existed in this country a growing tendency to adopt engines with Four Coupled wheels for the passenger trains on the great trunk lines, and for the mixed trains on shorter and branch railways: in the former case in consequence of the great number of passenger carriages required in many of the trains; and in the latter owing to the desirability of having engines of sufficient power to work trains composed partly of passengers and partly of goods. In most cases such engines have been built with small leading wheels and with the middle and hind wheels coupled, under the impression that it is safer to run at high speeds with wheels of small diameter in front than if their size were such as is usually employed when coupled for driving. In regard to the best distribution of weight upon the axles of such engines, it is evident that the difficulty is, whether in the case of inside or outside-cylinder engines, to get a fair proportion of weight upon the hind wheels so as to justify their being coupled to the middle wheels, assuming the position of the hind axle to be behind the firebox: and in order to show that this question is not easy of solution, the following instances are given of the distribution of weight upon the axles of such engines.

Fig. 6, Plate 25. Coupled Passenger engine with Outside cylinders 16 ins. diameter by 22 ins. stroke, middle and hind wheels coupled 5 ft. 7 ins. diameter, leading wheels 3 ft. 7 ins. diameter. Total weight 31·60 tons, of which the distribution is

Leading axle	10·80 tons	
Middle axle		11·85 tons
Hind axle		8·95 „
Total adhesion weight . .		20·80 „

the weight required for adhesion being 17·83 tons. In this engine a heavy cast iron block was added, forming the footplate, in order to obtain the above distribution of the weight.

Fig. 7, Plate 26. In the case of engines with Inside cylinders it is more easy to load the hind wheels sufficiently to prevent an exaggerated load upon the leading wheels; because the latter being placed more forward in the engine than is usually possible with outside cylinders, the weight on them is diminished, and when the middle axle is relieved from unnecessary weight by adjustment of the springs, a greater proportion is taken by the hind wheels than would be the case if the leading wheels were nearer the middle wheels. In such an engine with cylinders 15 ins. diameter by 20 ins. stroke, middle and hind wheels 5 ft. 6 ins. diameter, leading wheels 3 ft. 6 ins. diameter, total weight 25·80 tons, the distribution has been

Leading axle	8·39 tons	
Middle axle		10·00 tons
Hind axle		7·41 „
Total adhesion weight . .		17·41 „

the weight required for adhesion being 14·48 tons. In this engine extra weighting of the footplate as in the previous instance was not required.

Fig. 8, Plate 26. Another example of this class of engine is that in which the sloping of the bottom of the firebox upwards from front to back allows of the hind axle being placed under the ashpan, whereby it carries a much larger share of the weight of the engine than would otherwise be possible. Two instances of this kind are given, because the distribution seems a very advantageous one, and has been obtained without the addition of useless weight to the engine. An engine with cylinders 17 ins. diameter by 22 ins. stroke, middle and hind wheels 6 ft. 6 ins. diameter, leading wheels 4 ft. 0 ins. diameter, had the following distribution:—

Leading axle	9·86 tons	
Middle axle		11·57 tons
Hind axle		9·71 „
Total adhesion weight . .		21·28 „

the weight required for adhesion being 17·29 tons. In another engine, with the same size of cylinders and wheels, the distribution was

Leading axle	9·56 tons	
Middle axle		11·01 tons
Hind axle		9·80 „
Total adhesion weight . .		20·81 „

the weight required for adhesion being 17·29 tons.

When it is desired, as is not unfrequently the case, to construct such engines for carrying their own supply of fuel and water, it is easy so to arrange the position of the tanks as to get an excellent distribution of weight upon the wheels; and if the tanks be conveniently placed on the side frames pretty equally over the coupled axles, the loading and unloading of the coupled wheels in moderately equal proportions is secured, when the tanks are first filled and afterwards gradually emptied by the supply to the boilers: whereas, when the tank is placed under the footplate, the hind axle has a much larger proportion of the gross weight of the engine to carry when the tank is full than when it is empty. The weights obtained in an engine of this class, with cylinders 15 ins. diameter by 20 ins. stroke, middle and hind wheels 5 ft. 0 ins. diameter, leading wheels 3 ft. 6 ins. diameter, have been

Leading axle	8·50 tons	
Middle axle		10·13 tons
Hind axle		9·51 ,,
Total adhesion weight		19·64 ,,

the weight required for adhesion being 15·94 tons.

Fig. 9, Plate 26. One of the most generally useful classes of engine for the common purposes of railways is the six-wheeled engine having the Four front wheels Coupled, since it can be used for ordinary goods trains, or for heavy passenger trains when not run at too great a speed. The advantage of such an arrangement of engine, if made with Inside cylinders, is that nearly the whole weight of the engine may be conveniently distributed upon the four coupled wheels, leaving but a small proportion for the hind wheels, which in this case do little more than serve to avoid the disadvantages of an overhanging firebox. Where the load to be drawn permits the use of such an engine, the additional wear and tear necessarily following upon the adoption of six coupled wheels is obviated. The following is a good example of distribution of weight on the axles of an engine of this class, with inside cylinders 16 ins. diameter by 22 ins. stroke, leading and middle wheels 5 ft. 0 ins. diameter, hind wheels 3 ft. 6 ins. diameter:—

Leading axle		9·77 tons
Middle axle		10·27 ,,
Hind axle	4·42 tons	
Total adhesion weight		20·04 ,,

the weight required for adhesion being 19·91 tons.

Fig. 10, Plate 27. It is evident that by changing the relative positions of the leading and middle axles, the distribution of the weight in the last example may be varied as required without danger of getting a disproportionate length of connecting rod. But where such engines are to be constructed with Outside cylinders, a difficulty as to distribution immediately arises, since the large diameter of the front wheels renders it necessary that the leading axle be placed at a considerable distance behind the cylinders, and thus a much larger proportion of the weight of the engine is thrown upon the leading wheels than is either necessary or desirable. The distribution obtained in an engine with outside cylinders 15 ins. diameter by 22 ins. stroke, leading and middle wheels 4 ft. 6 ins. diameter, has been

Leading axle		10·00 tons
Middle axle		11·07 „
Hind axle	4·62 tons	
Total adhesion weight		21·07 „

the weight required for adhesion being 19·47 tons.

Engines of this class are sometimes required to carry their own supply of water and fuel, in which case it seems most desirable to place the water tank on the top of the boiler, so as to increase the load proportionately on the coupled wheels, and let the hind wheels carry the increased weight involved in the fuel boxes and fuel. This arrangement secures an equal increase and decrease in the proportion of the weight carried by the coupled wheels, as the tank is filled and emptied; and avoids the objection that arises in placing the tank under the footplate, from the great disproportion of the load upon the hind wheels when they carry nearly the whole weight of the water, fuel, and tanks. The distribution of weight in a "saddle" tank engine, having Inside cylinders 14 ins. diameter by 20 ins. stroke, leading and middle wheels 4 ft. 9 ins. diameter, is

Leading axle		9·60 tons
Middle axle		11·24 „
Hind axle	5·07 tons	
Total adhesion weight		20·84 „

the weight required for adhesion being 14·59 tons. Should it be desired to add tanks to engines of this class with Outside cylinders, it is clear that a certain amount of the superfluous weight upon the leading wheels might be counterbalanced by placing the tank under the footplate; but the disadvantage would still continue of disproportionately loaded axles, according as there was a greater or less quantity of water in the tank.

Fig. 11, Plate 27. The next class of engines to be referred to is that used for heavy goods traffic with all Six wheels Coupled.

Such engines constructed with Inside cylinders are very common, though a good distribution of weight upon their axles is not easy, since the hind axle when placed behind the firebox has naturally but a comparatively small proportion of the weight of the engine to carry; and if, in order to obviate this disadvantage, it is sought to move the middle axle nearer to the cylinders, the due length of the connecting rod is sacrificed, unless the length of the boiler be increased, giving a corresponding increase in the wheel base of the engine, which in railways having sharp curves is by no means desirable, especially in an engine having all the wheels coupled. A favourable distribution of weight in an engine of this kind with inside cylinders, 16 ins. diameter by 24 ins. stroke, and wheels 5 ft. 1½ in. diameter, is

Leading axle	10·60	tons
Middle axle	10·90	,,
Hind axle	7·25	,,
Total adhesion weight . .	28·75	,,

the weight required for adhesion being 21·18 tons, and the wheel base 16 ft. 3 ins.

Fig. 12, Plate 27. A large number of engines with Six Coupled wheels have been built with all their axles underneath the cylindrical part of the boiler, so as to attain the double object of a short wheel base and a more equal distribution of weight upon the axles. With such an arrangement the following have been the results in an engine with inside cylinders 18 ins. diameter by 24 ins. stroke, and wheels 5 ft. 0 ins. diameter:—

Leading axle	7·70	tons
Middle axle	10·35	,,
Hind axle	9·95	,,
Total adhesion weight . .	28·00	,,

the weight required for adhesion being 27·45 tons, and the wheel base 12 ft. 2 ins. The advantage so obtained of a short wheel base is however counterbalanced to a considerable extent by the instability created by the overhanging firebox, which, when the firebox is large, is a matter of serious importance.

Fig. 13, Plate 28. As a mean between the extremes of the last two examples stands the Six-wheeled Goods engine with long firebox having the grate sloping upwards from front to back. In this case not only is the wheel base shortened as compared with the engine shown in Fig. 11; but the weight on the hind axle, owing to its position under the ashpan, is increased as compared with engines having the hind coupled axle behind the firebox. The distribution of weight in such an engine, with inside cylinders 17 ins. diameter by 24 ins. stroke, and wheels 5 ft. 0 ins. diameter, has been

Leading axle	10·64 tons
Middle axle	11·57 „
Hind axle	9·73 „
Total adhesion weight . .	31·94 „

the weight required for adhesion being 24·53 tons, and the wheel base 15 ft. 6 ins.

Fig. 14, Plate 28. The construction of engines having Six Coupled wheels with Outside cylinders, although frequently met with on the continent, is in this country very unusual, since such an arrangement aggravates the disproportion between the weight upon the leading and that upon the hind axle, when the hind axle is placed behind the firebox; although in the cases where the axles are all under the boiler, the greater weight and more forward position of the outside cylinders tends in some measure to counterbalance the overhanging firebox. The distribution obtained in an outside-cylinder engine with overhanging firebox, having cylinders 17¼ ins. diameter by 24½ ins. stroke, and wheels 4 ft. 3 ins. diameter, has been

Leading axle	11·20 tons
Middle axle	10·46 „
Hind axle	10·95 „
Total adhesion weight . .	32·61 „

the weight required for adhesion being 30·35 tons, and the wheel base 11 ft. 0 ins.

For Mineral and Coal traffic, engines are frequently constructed having six wheels coupled and with tanks for their water and fuel supply. As in the case of other engines with the hind wheels coupled, so here the position of the tanks can be so arranged as to equalise the unfavourable distribution of weight upon the hind wheels when the hind axle is placed behind the firebox; since by fixing a long side or wing tank on each side of the engine over the middle and hind axles, it becomes possible to adjust the weight on these two axles in such a manner as to be somewhat in proportion to that upon the leading axle, when the fuel and water supply is at its average amount. The distribution of weight obtained in an engine of this class, with cylinders 16 ins. diameter by 24 ins. stroke, and wheels 4 ft. 6 ins. diameter, has been

Leading axle	9·80 tons
Middle axle	10·85 ,,
Hind axle	9·80 ,,
Total adhesion weight . .	30·45 ,,

the weight required for adhesion being 24·13 tons, and the wheel base 12 ft. 6 ins.

In some instances such engines are constructed with the tank under the footplate, but these are again subject to the disadvantage of too great a variation in the weight upon the hind wheels, depending upon whether the tank and fuel boxes are empty or full. In an engine built thus, with cylinders 16 ins. diameter by 22 ins. stroke, and wheels 3 ft. 10 ins. diameter, the distribution has been

Leading axle	8·40 tons
Middle axle	10·62 ,,
Hind axle	9·79 ,,
Total adhesion weight . .	28·81 ,,

the weight required for adhesion being 25·96 tons, and the wheel base 13 ft. 5 ins.

On Mineral railways having sharp curves it is frequently desired to reduce the wheel base to the smallest possible limit, and consequently all the axles of the engines are placed between the firebox and smokebox. Under these circumstances the tank has to be placed on the top of the boiler, and so arranged that whether full or empty each pair of wheels shall be proportionately loaded and relieved. The distribution of weight in such an engine, with inside cylinders 16 ins. diameter by 24 ins. stroke, and wheels 4 ft. 6 ins. diameter, has been

Leading axle	8·50 tons
Middle axle	11·00 „
Hind axle	10·75 „
Total adhesion weight	30·25 „

the weight required for adhesion being 24·13 tons, and the wheel base 11 ft. 8 ins.

Fig. 15, Plate 28. Bogie Engines have been rendered necessary by the construction of railways with not very heavy permanent way and sharp curves; in consequence of which a short wheel base has become a necessity, and in heavy engines it has been found requisite to carry the weight of the leading end upon four wheels instead of upon two, the wheels being placed very far forward and thereby necessitating considerable lateral freedom of motion upon the curves. Engines of this class working with tenders and having their middle and hind wheels coupled are used almost universally on the American railways, both for passenger and goods traffic. It appears that in engines so constructed a considerable amount of the weight of the engine which ought to be available for adhesion is carried on the bogie wheels, in consequence of the increased weight of the engine involved in the use and construction of the bogie, together with the heavy spark-catching chimney, and the usual cow-catcher in front, as shown in Fig. 15. An incidental objection to the use of bogies is the necessity for employing wheels of small diameter, so as to obtain clearance under the frames and cylinders, their diameter being usually less than that of the carriage and wagon wheels. The weights obtained in an engine of this kind, with outside cylinders 13 ins. diameter by 18 ins. stroke, and four coupled driving wheels 5 ft. 6 ins. diameter, have been

Bogie axles	8·00 tons	
Middle axle		8·50 tons
Hind axle		7·50 „
Total adhesion weight		16·00 „

the weight required for adhesion being 9·79 tons, and the wheel base 13 ft. 6 ins. from centre of bogie to hind wheel centre. When it is desired to carry a water tank in such engines, the tank may be so arranged as to throw all the additional weight upon the coupled wheels, and indeed as far as possible to equalise the weight upon them.

With regard to the general principles of distribution of weight upon the axles of six-wheeled locomotive engines, it seems to be the common opinion that the middle axle, to which the power is first applied from the cylinders, should carry the greatest weight, and next to this the leading axle, thus leaving the lightest load to be borne by the hind axle; this arrangement being thought desirable with a view to keep the front of the engine heavier on the rails than the hind end, and so secure it from risk of jumping off. The writer would however suggest whether such a necessity for placing a greater load on the leading than on the hind axle really exists; since it seems unlikely that any engine with a reasonable weight upon the leading axle, and consequently with a reasonably strong spring for keeping the wheels down on the road in the event of blows being received, could ever leave the line merely because the hind axle carried a greater amount of weight than the leading axle. It should further be remembered that in all cases where the hind wheels of an engine are coupled and the leading wheels not so, an arrangement which is becoming more and more frequent, it is absolutely desirable, in order to obtain the maximum adhesion, that the hind coupled wheels should carry a weight nearly equal to that upon the middle wheels, and consequently greater than that usually placed upon the leading wheels. In this respect there is a disadvantage in the employment of engines with outside cylinders, because of the greater weight of the front part of the engine in that arrangement, and the consequent loss of a larger proportion of the total weight for adhesion. This objection applies only to outside cylinder engines having their leading wheels uncoupled: but on the other hand to couple the leading wheels of such engines involves considerable complications and difficulties.

Another point of interest connected with the distribution of the weight is the effect produced upon the stability of a locomotive by the difference between the portion of weight carried upon each *spring* and the total weight carried by the *rail* at each wheel: in all the preceding examples of distribution that have been given, the weights stated are those upon the rails at each axle. In engines with inside cylinders this difference is often very considerable, and must exercise a great influence upon the tendency to rise and fall on the springs; and often when, in taking account of the weight upon the rails only, the front pair of *wheels* is found to press upon the rails with a less weight than the hind wheels, the fact is lost sight of that the weight upon the leading *springs* is greater than upon the hind pair, and the tendency to leave the road is consequently diminished in front. This arises from the circumstance that, in the case of the middle and hind coupled wheels, the weight of the parts not carried by the springs—namely the wheels, axles, axleboxes, springs, and gearing—is greatly in excess as compared with the weight of the corresponding parts not carried by the front springs. As an instance may be taken one of the engines already referred to, Fig. 8, Plate 26, being an inside-cylinder engine with cranked middle axle, having cylinders 17 ins. diameter by 22 ins. stroke, leading wheels 4 ft. 0 ins. diameter, middle and hind wheels coupled 6 ft. 6 ins. diameter. Here the weights upon the rails and upon the springs at the several axles were as follows:—

	Weight upon Rails.	Weight upon Springs.
Leading axle	9·36 tons . .	7·91 tons.
Middle axle	11·57 „ . .	7·77 „
Hind axle	9·71 „ . .	6·78 „

thus showing that the mass of the engine above the springs, and having liberty to leave a line parallel to the plane of the railway, had a sufficient excess of weight in front to "keep down the nose," amounting to 1·13 tons excess of weight upon the leading springs as compared with the hind springs; although the weight obtained for adhesion by coupling the hind wheels was 0·35 ton greater than if the front wheels had been coupled instead. In this example the proportion of the weight carried on the springs to the total weight upon the rails at each axle was, at the leading axle 85 per cent., at the middle axle 67 per cent., and at the hind axle 70 per cent.; the total weight carried upon the springs being 73 per cent. of the total weight on the rails.

The difficulties now presented to the proper distribution of weight upon the axles of locomotives are considerably increased by the prevalent adoption of sharper curves in the construction of railways than were formerly used, and the consequent necessity for shortening the wheel base. Continental engineers have been driven by similar difficulties to adopt in a large number of cases the plan of placing all the axles of the engine under the cylindrical part of the boiler, thus gaining a short wheel base by letting the firebox overhang behind. This plan is liable to considerable objection, on account of overloading the hind axle of the engine to such an extent as to cause a galloping motion when running fast; and as it has now become more necessary, from the introduction of coal as fuel and for other reasons, to adopt fireboxes of larger dimensions and increased weight, the objection to their overhanging the hind axle has been proportionately increased. At the same time the arrangement of sloping firegrate already referred to greatly facilitates the adjustment of weight upon the hind wheels; since, when the frames are placed outside the wheels, the axle may pass across under the firebox at any point necessary to bring the desired weight upon it, so that not only is the long wheel base avoided, but also the overhanging of the firebox; while the instability of the engine consequent upon the latter is guarded against. An unavoidable weight is often thrown upon the leading uncoupled axles of locomotives by the obligation of keeping the middle axle sufficiently far back to get adequate length of connecting rod: hence it becomes necessary in some instances either to increase the length of the boiler in order to obtain sufficient weight behind the middle axle, thus involving a considerable lengthening of the wheel base; or else to adopt the heavy sloping firebox accompanied by outside frames.

By care in arranging the position of the middle axle of a locomotive in relation to the centre of gravity of the mass carried upon the springs (not the centre of gravity of the whole engine) a fair distribution of the weight may usually be secured. It is evident that only the portion of the engine above the springs can be affected by the adjustment of the spring attachments; and it will be found that the centre of gravity of this portion varies to the extent of some inches from that of the whole mass of the engine. Taking then as a basis the centre of gravity of this adjustable portion of the engine, the effect produced upon the distribution of the load by any alteration either in the position of the axles or in the screwing up of the spring links can be readily calculated by dividing the total adjustable load in such proportions that the products of the several loads upon the axles multiplied by their respective distances from the centre of gravity shall balance one another on each side of that centre.

In the following example the results thus obtained by calculation were verified by the actual weights upon a weighing machine, in the case of a single passenger engine, having the centre of gravity of the adjustable load 8½ inches in front of the middle axle, as shown at G in Fig. 16, Plate 29, the leading axle being 6 ft. 8 ins. in front of the middle axle, and the hind axle 8 ft. 0 ins. behind it. The several distances of the axles from the centre of gravity were consequently, leading axle 71½ ins. forward, and middle and hind axles 8½ and 104½ ins. respectively backward, as shown in Fig. 16. The middle driving springs were screwed up in the three weighings according to the several different adjustments enumerated, the load then apportioning itself correspondingly at the leading and hind axles, as follows:—

	Leading axle. Tons.		Middle axle. Tons.		Hind axle. Tons.		Total Weight. Tons.
1st weighing	11·85	+	10·20	+	8·05	=	30·10
2nd "	10·55	+	12·50	+	7·05	=	30·10
3rd "	9·65	+	14·20	+	6·25	=	30·10

These being the actual results ascertained by the weighing machine, the following are the results obtained by calculation of the distribution of the weight, starting in each case with the respective loads above given at the middle axle. The constant weight at the several axles (that is the weight of the wheels, axle, axleboxes, springs, and gearing) was, leading 1·76 tons, middle 3·66 tons, and hind 1·68 tons; total 7·10 tons, leaving 23·00 tons adjustable weight above the springs.

Calculated Distribution of Weight.

		Leading axle.	Middle axle.	Hind axle.	Total Weight.
		Tons.	Tons.	Tons.	Tons.
1st weighing. 10·20 tons at Middle axle. (*See Note* A.)	Adjustable weight	10·09	6·54	6·37	23·00
	Constant „	1·76	3·66	1·68	7·10
	Total . . .	11·85	10·20	8·05	30·10
2nd weighing. 12·50 tons at Middle axle. (*See Note* B.)	Adjustable weight	8·83	8·84	5·33	23·00
	Constant „	1·76	3·66	1·68	7·10
	Total . . .	10·59	12·50	7·01	30·10
3rd weighing. 14·20 tons at Middle axle. (*See Note* C.)	Adjustable weight	7·91	10·54	4·55	23·00
	Constant „	1·76	3·66	1·68	7·10
	Total . . .	9·67	14·20	6·23	30·10

The effect that would be caused in relieving the leading axle of a portion of the weight by shifting the position of the middle axle in this engine is ascertained by the following calculation for a case of shifting the axle 6 ins. more forward, as shown by the dotted position in Fig. 16, Plate 29, in the instance of the second of the above adjustments of the middle springs, with 12·50 tons total at the middle axle :—

(*See Note* D.)	Leading axle.	Middle axle.	Hind axle.	Total Weight.
	Tons.	Tons.	Tons.	Tons.
Adjustable weight . .	8·53 . .	8·84 . .	5·63 . .	23·00
Constant „ . .	1·76 . .	3·66 . .	1·68 . .	7·10
Total	10·29 . .	12·50 . .	7·31 . .	30·10
In place of the Actual weights	10·55 . .	12·50 . .	7·05 . .	30·10

the effect produced being therefore a transference of ¼ ton from the leading to the hind axle by shifting the middle axle 6 ins. forwarder.

Tons. Ins. Tons. Ins. Tons. Ins.

Note A. 10·09 × 71½ = (6·54 × 8½) + (6·37 × 104½)

„ B. 8·83 × 71½ = (8·84 × 8½) + (5·33 × 104½)

„ C. 7·91 × 71½ = (10·54 × 8½) + (4·55 × 104½)

„ D. 8·53 × 71½ = (8·84 × 2½) + (5·63 × 104½)

The respective leverages are marked in Fig. 16, Plate 29.

In the case of engines with the middle and hind wheels coupled, Compensating or Connecting Levers are frequently employed, as shown in Fig. 17, Plate 29, for the purpose of equalising the weights on the two driving axles. The back end of the middle spring and the front end of the hind spring are connected together by the lever, which is attached to the frame of the engine by a centre pin A on which it vibrates, the other two ends of the springs being each connected direct to the frame as usual. When the two arms of the lever are equal in length, the weights carried by the two springs are necessarily rendered equal, however different they may have been when the springs were attached direct to the frame at both ends, before connection by the lever; because the forces of tension at the two ends of an equal-armed lever must always be equal. This change in the distribution of the load is produced by the more heavily loaded middle spring becoming partially released from compression, adding at the same time to the compression of the more lightly loaded hind spring through the action of the connecting lever, as shown in Fig. 18. The effect of the connecting lever is thus to blend the two springs into one, and to produce the same distribution of load as if the middle and hind axles were removed and replaced by a single axle fixed in the position of the axis A of the connecting lever and carrying their combined load; thereby transforming the engine in effect into a four-wheeled engine. Exactly the same result however can be produced without the connecting lever, by simply screwing up the hind spring to the same extent as it is compressed by the action of the lever, and slacking back the middle spring to the corresponding extent. But the objectionable result then arises in both cases alike, that a portion of the load of which the middle wheels are relieved is thrown upon the leading wheels, thereby causing the loss of so much of the total driving adhesion; since the leading axle is the fulcrum upon which the engine is lifted when screwing up the hind springs, as shown by the diagram, Fig. 19, Plate 29. Where the connecting lever is inserted between the leading and middle springs, the same remark applies to the effect produced on the distribution of the weight as where the middle and hind springs are connected by a lever: that no distribution of the weight is thereby obtained which cannot be equally obtained with independent springs. It has to be remarked however that, in consequence of the engine being transformed virtually into a four-wheeled engine by the insertion of connecting levers, the original distribution of the weight can never be altered in any degree after the engine is built and fitted with the levers; whereas with independent springs the six-wheeled engine retains the full advantage of its three axles, whereby the original distribution of the weight can be altered at any subsequent time within a very extensive range, as is seen by the example already given of the three weighings of the same engine. Moreover with a connecting lever of equal arms, although the weights upon the connected springs are rendered equal, the pressure of the wheels upon the rails and consequently their adhesion will still be unequal, on account of the greater weight of the middle axle and gearing.

These conclusions are illustrated by the following examples, obtained by actual trials of the distribution by means of the accompanying working model, constructed for the purpose of demonstrating the real action of the connecting lever. The model represents an engine frame supported by spring balances at three points corresponding to the position of the three axles in the engine, and weighted by adjustable weights at the point where the centre of gravity of the portion of the engine above the springs would be situated, with a connecting lever of equal arms between the middle and hind, or the leading and middle springs, capable of being thrown in or out of action as desired; the scales of the spring balances thus affording a ready means of reading off accurately the actual distribution of the weight at each spring in the several trials. The model was weighted to represent an engine having an adjustable weight of 22·37 tons, with the centre of gravity in front of the middle axle; and the connecting lever was inserted first between the middle and hind springs, and afterwards between the leading and middle springs. The weight was first distributed on the several springs by means of the spring links alone, the connecting lever being fixed so as to be out of action; the lever was then released and thrown into action, when the weight assumed the new distribution recorded; after which this last distribution was again effected by means of the independent springs, the connecting lever being thrown out of action as before. The slight discrepancies in the results arose from the friction of the model, which could not be entirely got rid of.

With the connecting lever between the middle and hind springs, the following were the results read off from the spring balances:—

	Leading spring. Tons.		Middle spring. Tons.		Hind spring. Tons.
Original distribution without connecting lever	9·37	.	9·00	.	4·00
Lever in action	11·12	.	5·72	connected	5·52
Same distribution with independent springs	11·11	.	5·73	.	5·51

With the connecting lever between the leading and middle springs, the results obtained were the following:—

	Leading spring. Tons.		Middle spring. Tons.		Hind spring. Tons.
Original distribution without connecting lever	10·00	.	7·50	.	4·87
Lever in action	9·13	connected	9·10	.	4·13
Same distribution with independent springs	9·12	.	9·10	.	4·17

The above results show therefore that nothing is gained by the application of the connecting lever in equalising the loads on the connected springs that cannot be also obtained without the lever by independent springs. This is a point of some importance to be clearly realised, because an opinion has prevailed that the use of the connecting lever gives facilities not otherwise to be obtained for adjusting the distribution of the weight.

The first of the above examples, with the connecting lever between the middle and hind springs, shows also the effect of the equal-armed lever in that case in throwing an increased weight upon the leading spring: for while the middle spring is relieved to the extent of 3·27 tons load, only 1·52 tons of this is added to the compression of the hind spring, and the difference, 1·75 tons, is all thrown upon the leading spring. This case is illustrated by the diagrams in Plate 29, where Fig. 17 shows the position of the springs in the original distribution without the connecting lever A being in action; and Fig. 18 represents the result of the lever coming into action, the hind spring being thereby further compressed, the middle spring relieved, and an additional load thrown upon the leading spring.

The use of the connecting lever has however an independent advantage in passing over an inequality in the rails, because the second spring connected by it partly shares in each deflection of the first spring, and the play of the first spring is thereby diminished to that extent; but the same result is attained with independent springs, by employing proportionately longer springs wherever practicable. It has to be noticed moreover that with the connecting lever the objection is incurred of causing the breaking down of both springs in the event of the failure of either of them. In connecting the leading with the middle springs, levers with unequal arms have sometimes been employed, the length of the arms being inversely proportionate to the loads on the two springs, so that the distribution of the load is not disturbed by inserting the levers. In this case the levers have the same action as before of lessening the play of the springs in running over any inequality in the rails; but the same objection of causing a break down of both springs by any failure of either applies as before, though with greater force in the case of the leading springs on which the safe running of the engine depends.

Mr. **Robinson** exhibited the working model constructed for the purpose of illustrating the action of the connecting lever, and showing that any distribution of the weight obtained with the connecting lever was effected equally well with independent springs by a corresponding adjustment of the spring links. The particular case of a six-wheeled engine with the four hind wheels coupled, having the centre of gravity in front of the middle axle, was illustrated by means of the model, and it was shown that the insertion of a connecting lever to equalise the weights on the middle and hind wheels caused an actual loss of driving adhesion, by throwing an increased load on the leading wheels.

The **Chairman** observed that it appeared the only point gained by the use of a connecting lever was that it ensured that the distribution of the load between the connected wheels in running should always remain in the proportion originally determined upon by the length of the arms of the lever: but nothing was gained as regarded the actual distribution of the load on the several wheels, which could not be accomplished as well by a proper adjustment of independent springs. He enquired to what extent the friction of the connecting lever was found to affect the correct distribution of the load upon the springs between which it was placed.

Mr. **Robinson** replied that where the connecting lever was constructed to turn upon a round centre pin fitting into a hole in the lever, the friction was so great from the very heavy pressure upon the small surface of the pin that the results obtained in the model could not be realised by actually weighing the engines, and consequently the intended distribution of the weight by the lever was not really maintained in practice. In some of the Great Western engines fitted with connecting levers this friction had been reduced by using knife-edge bearings for the levers, instead of the round centre pins; but still the friction of the axleboxes between the guards was found to interfere very much with the intended results being obtained.

Mr. C. W. **Siemens** remarked that the friction would no doubt have the effect of preventing the due action of the connecting lever while the engine was at rest; but he thought that in running the shaking produced would impart to the lever a concussive motion favouring its speedy adjustment to the varying conditions of load which it was intended to equalise.

Mr. F. W. Webb observed that the results obtained by the model were corroborated in practice, as regarded the increase of weight thrown upon the leading wheels where a connecting lever was placed between the middle and trailing wheels: he had known several cases of such engines where the connecting levers had been taken off, and it had been found that 1½ tons had been removed from the leading wheels by the change, and added upon the driving wheels. He might mention that some four-wheeled inside-cylinder tank engines had been constructed by Mr. Ramsbottom for shunting at various stations on the London and North Western Railway, having the firebox entirely inside the cylindrical barrel of the boiler, so that the hind axle could be carried back far enough to give an exactly equal distribution of weight on the front and hind wheels. The firebox was cylindrical and made of Bessemer steel, and the tubes were also steel; and the steam was as dry as from an ordinary boiler with low firebox. These engines had been at work some time, but for shunting purposes only, not being able to make steam fast enough for running.

Mr. Colburn said that connecting levers were used in all American locomotives, not so much in reference to the distribution of the weight as to promote the ease and steadiness of the engines in running over rough lines: and there was no doubt that whether on rough or smooth lines the engines worked better with them. The American engines always had a bogie in front, according to the diagram exhibited, and engines of that construction had been brought over for working the Birmingham and Gloucester line many years ago. In some early American engines the driving wheels were placed behind the firebox; and afterwards, as the engines grew heavier, a second pair of driving wheels was added in front of the firebox, with an independent spring for each wheel. Several engines were built on this construction, but they did not seem to answer; and some of these were altered by Mr. Harrison, the inventor of the cast iron boiler that had been described, by putting in a connecting lever, which was placed above the wheels, the ends bearing upon the axleboxes, with an inverted spring between the wheels, attached by links to the lever: he built a large number of locomotives on that plan in St. Petersburg for the St. Petersburg and Moscow Railway.

There was a large amount of weight below the springs in American locomotives, as they were made with cast iron driving wheels, which were very heavy, and the tyres were found to stretch in consequence unless they were put on very thick. In an engine of 28 tons weight there was about 6 tons below the springs, in the four driving wheels with their axles and axleboxes; and with the addition of the bogie there was thus about one third of the whole weight of the engine that was not relieved by springs at all. The wheels were now made with wood blocks under the tyres, cut cross grain of the wood, as a bed for the tyres upon the wheels, in order to reduce the injurious effect of their great weight and rigidity in passing over any inequalities in the road. The wheel base of the bogie was generally about the same as the gauge of the line, from 5 ft. 3 ins. to 5 ft. 6 ins.; and the wheels themselves were usually 2 ft. 9 ins. diameter, the same as those on the bogies of the carriages; sometimes they were as small as 2 ft. 2 ins. diameter. The usual distribution of the weight was about 3-5ths on the driving wheels, and 2-5ths on the bogie, or sometimes 2-3rds on the driving wheels, and 1-3rd on the bogie: the position of the pivot of the bogie, being so far forward, allowed of keeping the driving wheels further back, whereby a shorter coupling rod and longer connecting rod could be used.

The practical effect of the connecting levers in running was to ease the motion of the engine, which was much needed on the bad roads of the American railways. He had himself experienced their beneficial action in travelling on the engine from Augusta to Atlanta, 171 miles, over a very rough road, and all the time of running the connecting levers were in a complete dance with continued oscillations, but the engine ran very smoothly and steadily. The engines had to be hung with greater provision for elasticity for running over those rough roads, and skeleton springs with open plates were generally used, the spring hangers being also supported on india-rubber washers. In some instances the connecting lever itself was a spring, which made the footplate of the engine very easy in running.

Mr. W. M. **Neilson** considered the connecting levers were without doubt a valuable adjunct to an engine for running on bad roads; but as far as the distribution of the weight was concerned they certainly had no advantage over independent springs, and in the case that had been pointed out in the paper they had the disadvantage of throwing an increased load upon the leading wheels while diminishing at the same time the driving adhesion. He could fully confirm what had been stated as to the effects of the connecting lever in the American engines, having travelled over many of the American railways on the ordinary four-wheel-coupled bogie-engines fitted with the levers, and at a good speed of running there was not any objectionable unsteadiness in the engine, notwithstanding the rough state of the roads: but he should not have thought it safe to run at the same speed with an ordinary English locomotive over the same description of road. Even on the English lines he thought the connecting levers would give an advantage in smoothness of running, as the road could not be maintained always in the very best condition, and was by no means perfect at its best. The action of the levers was beneficial both to the permanent way and to the engine itself, by reducing the effect of shocks arising from inequalities of the road; and in the same manner they conduced to the safety of the engine in running, rendering it less easy for the wheels to leave the rails. With independent springs the effect of running over an obstacle or elevation in the rails was to lift the engine in proportion to the rigidity of the springs; but if the same springs were connected by a lever, each would be deflected only half the amount, and the engine would be lifted only half as much as before.

Mr. **Robinson** observed that the effect of the connecting lever when the engine ran over an obstacle was to cause the two connected springs to be both deflected simultaneously, so that the engine would be lifted a smaller amount by the shock than if one spring only had been acting at a time. The lever had thus the effect of virtually doubling the length of each spring; and although the same result of a small lift might be obtained without the lever if springs of double the length were used, yet the length of spring was practically limited in an engine by the confined space, so that the springs were often not more than 2 ft. 6 ins. long, and in such cases the connecting lever had the advantage of practically lengthening the short springs.

Mr. E. Reynolds did not think that any lengthening of the springs would give the same ease of motion that was obtained by a connecting lever. In the Bloomer engines of the London and North Western Railway having connecting levers between the leading and middle springs, the leading wheels were heavily loaded with about 11½ tons upon them; and the extreme amount of inequality likely to be met with in the rails on English lines might be taken at ½ inch, which corresponded to an additional load or compression of 4 or 5 tons upon the springs, as they were very short and rigid. Hence a rise of ½ inch in the rails would cause 4 or 5 tons greater pressure upon the rails for the moment at that point; but by the connecting levers the leading and middle springs would share the additional weight between them under all circumstances, and so relieve both the rails and the engine from a great part of the shock that would otherwise be felt, the engine being lifted only by the amount of rise at the centre of the lever.

Mr. Colburn remarked that connecting levers were used upon all the bogies in America both for engines and carriages; and the bogie itself having also the effect of reducing any disturbance by one half, the result of an inequality of ¼ inch in the rails would be to lift the centre of gravity of the engine or carriage only 1-8th inch. In the long carriages the distance from centre to centre of the bogies was 32 feet, and the carriages were also much lower than on English railways; the result was that they ran with greater steadiness, though the speed was certainly not so great as in the fast trains in this country.

The Chairman remarked that upon the American railways, which were comparatively speaking imperfectly constructed and laid down more with the object of covering a great extent of country than with a view to permanent durability of the works, the necessity for the use of connecting levers must have been much more strongly felt than in England; and hence the general adoption of the bogie, which was itself a connecting lever, both for engines and carriages. He had many engines running with connecting levers on the London and North Western Railway, but had not found that they ran more steadily on that line apparently than engines without the levers; though there could be no question that the introduction of the levers would reduce the disturbance of the engine to a certain extent where the road was not in first-rate condition. Any such arrangement was however in his opinion as much worse for the road as it was better for the engine.

He proposed a vote of thanks to Mr. Robinson for his paper, which was passed.

The Meeting then terminated.

PROCEEDINGS.

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2 AND 3 AUGUST, 1864.

The ANNUAL PROVINCIAL MEETING of the Members was held in the Institution Rooms, St. George's Place, Glasgow, on Tuesday, 2nd August, 1864; ROBERT NAPIER, Esq., President, in the Chair.

The Minutes of the last General Meeting were read and confirmed.

The PRESIDENT announced that the Ballot Lists had been opened by the Committee appointed for the purpose, and the following New Members were duly elected:—

MEMBERS.

JAMES GEORGE BECKTON,	Whitby.
JAMES CAMPBELL,	Matlock.
THOMAS EDWARD DUNN,	Allahabad, India.
ANTONIN ETIENNE,	Seville, Spain.
WILLIAM EDWARD EVERITT,	Birmingham.
THOMAS FLEET,	Westbromwich.
JOHN FRANKISH,	Manchester.
WILLIAM ISAAC HETHERINGTON,	Manchester.
SAMPSON ZACHARY LLOYD,	Wednesbury.
WILLIAM MARTLEY,	London.
ROBERT RAMAGE,	Dublin.
DUNCAN SHAW,	Cordova, Spain.
THOMAS SPITTLE,	Newport, Mon.
JAMES SWINDELL EVERS SWINDELL,	Brierley Hill.
THOMAS THOMAS,	Pontypool.

HONORARY MEMBERS.

Charles T. Parsons, . . .	Birmingham.
Abel Peyton, ...	Birmingham.

The following paper, by Mr. James M. Gale of Glasgow, Resident Engineer of the Water Works, communicated through Mr. Walter M. Neilson of Glasgow, was then read:—

ON THE MECHANICAL APPLIANCES OF THE LOCH KATRINE WATER WORKS FOR THE SUPPLY OF GLASGOW.

By Mr. JAMES M. GALE, of Glasgow.

Previous to 1860 that part of Glasgow lying on the north bank of the river Clyde, or about three fourths of the whole city, was supplied with water drawn from the river at two pumping stations 2½ and 3½ miles above Glasgow Bridge respectively. The remaining part of the city, that on the south side of the river, was supplied, and in greater part is still supplied, by the Gorbals gravitation works, established in 1847 on a small stream about 7 miles south of the city. The impure quality of the water drawn from the river had induced the corporation of Glasgow to purchase the whole of the works from the two existing water companies, and to promote a scheme for supplying the city from Loch Katrine, the well known Loch in the Perthshire Highlands. The works were commenced in 1856, were opened by Her Majesty on the 14th October 1859, and were completed and the water introduced to the greater part of Glasgow early in 1860. The whole works were executed from the designs and under the superintendence of Mr. J. F. Bateman.

Fig. 1, Plate 30, is a general plan showing the drainage area of Loch Katrine and the adjacent Loch Vennachar, together with the two smaller Lochs, Achray and Drunkie, and the inlet at A from Loch Katrine to the line of aqueduct.

Fig. 2, Plate 31, is a general plan showing the entire line of aqueduct for conveying the water from Loch Katrine to Glasgow.

Fig. 3, Plate 32, is a longitudinal section along the entire course of the works from Loch Katrine to Glasgow, showing the situation of the principal tunnels, aqueduct bridges, and syphon pipes throughout the course of the aqueduct.

The drainage area to the Loch Katrine Water Works amounts to 45,800 acres, or about 72 square miles, as shown in the plan, Fig. 1, Plate 30; and includes Loch Katrine, Loch Achray, Loch Vennachar, and Loch Drunkie. Loch Achray has not been appropriated for the use of the water works, but works have been constructed at the outlets of the three other lochs whereby a large amount of storage has been obtained at comparatively little cost. A masonry dam with four sluices and a waste weir 100 feet long have been erected at the outlet of Loch Katrine at the point marked B in the plan, Fig. 1. The level of the water is thus raised 4 feet above its former summer level, and the sluices also admit of the water being drawn down 3 feet below the former summer level; thus giving a control over the contents of the loch to the extent of 7 feet in depth, and a storage capacity amounting to 910 million cubic feet. The portions shown black around the margin of the loch in Fig. 1 indicate the additional area of water obtained by the raising of the loch, as also in the case of Loch Vennachar and Loch Drunkie. The drainage area to Loch Katrine alone is 22,800 acres, and the area of the loch itself at its summer level 3000 acres, or about one seventh of the whole drainage area. The district is very rugged and mountainous, as seen from the plan, Fig. 1, and the longitudinal section, Fig. 3; and in some places, especially near the pass of the Trosachs, very picturesque. The level of the water in Loch Katrine is 362 feet above the level of the sea; and the lip of the basin which surrounds it, except near the point A, Fig. 1, where the water is drawn off into the aqueduct, has a minimum elevation of 1000 feet above the sea, and at one place, Ben Venue, rises to 2388 feet. The rocks of the district are mica schist, one of the primary deposits, and are precipitous, very hard, nearly insoluble, and yielding water of great purity. The water drawn from the loch contains only about 2¼ grains of soluble matter per gallon and has a hardness of 0·8° on Dr. Clark's scale; in which a hardness of 1° is that due to one grain of chalk dissolved in one gallon of distilled water, the hardness being the property of destroying soap. The district contains very little land that can be cultivated, and the covering of soil or peat on the top of the rock is not deep enough to affect the colour of the water in the loch, even during high floods. Also there need be no apprehension of the quality of the water ever becoming injured by agricultural operations, or by drainage from populous districts: at present there are only ten houses on the 36 square miles of country which drains into the loch. The fall of rain in the district is very great: in the valley of the Duchray on the eastern side of Ben-Lomond, Fig. 1, and in Glen Gyle at the head of Loch Katrine, there is in some years a fall of 100 inches; while in the more open country lower down the valley the fall is about six tenths of that higher up. The table appended shows the amount of rainfall at several points, since rain gauges were established in the district.

The works at the lochs have been arranged on a scale sufficient to ensure a supply to Glasgow during the driest season of 50 million gallons a day, and to provide compensation water to the river Teith in addition. The supply for the city is drawn exclusively from Loch Katrine, and the compensation water principally from Loch Vennachar and Loch Drunkie. The compensation water was fixed by agreement with the proprietors and others having an interest in the rivers Teith and Forth at 40,500,000 gallons per day, or an average of 4500 cubic feet per minute, to be given out from Loch Vennachar at the rate of 6000 cubic feet per minute from 1 o'clock a.m. to 1 o'clock p.m., and 3000 cubic feet per minute from 1 p.m. to 1 a.m. of each day in the year.

This additional quantity of water has been obtained by constructing a masonry dam at the outlet of Loch Vennachar, at the point C in the plan, Fig. 1, Plate 30, with a waste weir 150 feet long. This is shown in Figs. 4 to 6, Plates 33 and 34. The dam is 110 feet long, Fig. 4, Plate 33, and is furnished with eleven cast iron sluices to regulate the flow of the water, the top of the dam being carried up and roofed in to form a protection for the working gearing of the sluices. The loch has been raised by the dam 5 feet 9 inches above its former summer level, and it can be drawn down by the sluices 6 feet below the summer level. A new channel was cut for the river, as shown at C in the plan, Fig. 1, 700 yards long and 50 feet wide, in order to allow of the water in the loch being drawn down to this further depth. The compensation gauge weir, placed at the lower end of the new river channel, consists of a continuous cast iron plate 100 feet long, brought to a thin edge at top, over which the water flows with a depth of 3¼ to 5¼ inches when the statutory quantity only is being discharged. The area of Loch Vennachar at its former summer level was 865 acres, and at the level to which it has been raised it is about 1000 acres, as shown by the black portions round the margin of the loch in the plan, Fig. 1. The storage capacity included in the range of level of 11 feet 9 inches depth afforded by the works is 425 million cubic feet.

The works at Loch Drunkie, Fig. 1, Plate 30, consist of two earthen embankments with puddle in the centre of each, protected by stone facing on the inner slopes in the usual manner. The northern embankment is 150 yards long, and the other, which is at the original outlet of the loch, is 40 yards long. The level of the loch has been raised 25 feet, and the area increased from 78 to 137 acres, as shown by the black portions surrounding the loch in Fig. 1, thus affording storage to the extent of 120 million cubic feet. The water is discharged from the loch by a cast iron pipe, 24 inches diameter, laid through the deepest embankment.

The total amount of storage provided by the works at the three lochs is therefore 1455 million cubic feet, equal to a supply for 100 days of 50 million gallons per day for the city and 40½ million gallons per day for compensation water to the river Teith, without taking into account the natural flow of the streams running into the lochs. At the present rate of consumption of water in the city, this storage is equal to 152 days' supply, including the compensation water.

As the Teith is a good salmon river, it was necessary to provide for the passage of the fish at the masonry dams at the outlets of Loch Vennachar and Loch Katrine. This has been done at Loch Vennachar by forming four salmon stairs at different levels to suit the varying level of the loch, of a width of 6 feet between the side walls. These are shown at D D in Fig. 4, Plate 33; and a longitudinal section of the highest one is shown in Fig. 5, Plate 34. The stairs have a general inclination of 1 in 12, and terminate at the upper end next the loch with cast iron sluices, which open by being moved downwards, thus allowing the water to fall over as over a weir. The detail of one of these salmon sluices is shown in Figs. 7 to 9, Plate 35. The sloping channels are formed into a succession of deep pools by planks upon edge placed across the channel, as shown at E E in Fig. 5, Plate 34, over which the water falls a depth of from 15 to 20 inches to the lower level. At Loch Katrine there are only two of these salmon stairs, but otherwise the arrangements are similar.

The point of inlet A, Fig. 1, Plate 30, where the water is drawn from Loch Katrine into the aqueduct for the supply of the city, is about 5 miles from the bottom of the loch and 2½ miles from the top. The water is first admitted from the loch into a basin 55 feet long by 40 feet wide inside, through three cast iron sluices, each 4 feet square. Across the middle of the basin is fixed a line of strainers, to keep fish &c. from passing from the loch into the aqueduct. The outlet sluices at B and C, Fig. 1, for discharging the water from the outlets of Loch Katrine and Loch Vennachar, as well as the inlet sluices from Loch Katrine to the aqueduct, are of similar construction. One of the inlet sluices is shown in Figs. 10 to 12, Plates 36 and 37. The cast iron sluice plate F is faced with brass, and works against brass faces on the cast iron frame G, which is securely let into the masonry and is furnished with guides to keep the sluice F in its place. The sluice is raised and lowered by means of the iron screw H working in a brass nut, the screw being turned by a crank and bevil wheels at top.

The length of the aqueduct from Loch Katrine to the service reservoir at Mugdock near Milngavie, as shown on the general plan, Fig. 2, Plate 31, is 25¾ miles, and from this reservoir to Glasgow is about 8 miles more; making a total length from Loch Katrine to Glasgow of about 34 miles. The built and tunnelled part of the aqueduct is 22 miles long; it is 8 feet high by 8 feet broad, as shown in the sections, Figs. 13 to 15, Plate 37, and has a uniform inclination towards Glasgow of 10 inches per mile or 1 in 6336, as shown in the longitudinal section, Fig. 3, Plate 32; and it is all capable of passing 50 million gallons per day. The valleys of the Duchray, the Endrick, and the Blane, Fig. 3, which are crossed by the line of aqueduct and prevent a uniform inclination being obtained throughout, make up an aggregate length of 3¾ miles, and are passed by cast iron syphon pipes 48 inches diameter with a mean fall of 1 in 1000 between their extremities. These pipes deliver a little over 20 million gallons per day; and at all the bridges and other places where masonry was required, provision has been made for laying two additional lines of pipes when the increased consumption of water in the city may require this to be done.

The first work on the line of aqueduct upon leaving Loch Katrine is a tunnel through the ridge which separates the valley of Loch Katrine from that of Loch Ard, Fig. 3, Plate 32. The point where the valleys approach nearest to each other was chosen, but even there the length of tunnel required is upwards of 1¼ mile, and it is at a depth of more than 500 feet below the top of the hill. Twelve shafts were sunk on the line of tunnel to facilitate the work, five of them being about 450 feet deep. The rock passed through in this tunnel, and in the greater part of the first 10 miles of the aqueduct, which is principally a series of tunnels, is mica slate of the hardest description. Along the margin of Loch Chon the work at some of the faces did not progress at a greater rate than 3 lineal yards in a month, although it was carried on night and day. The cost of the gunpowder alone used in the contract, which extended 7½ miles from the loch, was £10,540; and the average cost of the aqueduct for the same length was more than £13 per yard or £23,000 per mile. Figs. 13, 14, and 15, Plate 37, show sections of the aqueduct at different parts.

The three main valleys on the line of aqueduct are passed by cast iron syphon pipes, as already mentioned; but the minor ravines in the first 10 miles of the aqueduct are crossed by aqueduct bridges of iron. Besides a number of smaller ones there are five extensive aqueduct bridges of this kind, one of which, near Culegarton, Plates 31 and 32, is shown in Figs. 16, 18, and 19, Plates 38 and 39. It consists of a wrought iron tube I, 8 feet broad and 6½ feet high inside, extending over the deeper part of the ravines, supported at intervals of 50 feet by stone piers; and a cast iron trough J, also 8 feet broad and 6½ feet high, supported on a dry stone rubble embankment at either end of the wrought iron tube I, extending over the remaining part of the valleys where the ground is not so much depressed. The bottom and sides of the wrought iron tube I are 3-8ths inch thick, and the top 7-16ths inch thick, the whole being strengthened by angle and T iron. The plates of the cast iron trough are 5-8ths inch thick, the dimensions of the largest being 4½ feet by 4 feet, and they are connected and strengthened by flanges with rust joints. The level of the wrought iron tube I is about 3 feet lower than that of the cast iron troughs J J at each end, so as to ensure the tube being always completely filled with water up to the top, in order that the top of the tube may be kept always at the same temperature as the sides, and the tube may not be racked by the strain that would arise from the top plates becoming heated by the sun if the water were not in contact with them. In order to allow of emptying the tube at any time, for painting or other purposes, a discharge valve K, Figs. 18, 21, and 22, is provided at one end of the tube, by which the water can be run off into the valley beneath.

The junction between the wrought iron tube and the cast iron trough is shown in Figs. 21 and 22, Plates 40 and 41, and in detail enlarged in Figs. 23 and 24, Plate 42. It is made by bolting the cast iron trough to a cast iron bed-plate L, Figs. 21 and 23, and to upright cast iron standards M M, Figs. 22 and 24, at each side. The wrought iron tube rests upon a bolster of vulcanised india-rubber placed in a groove in the bed-plate L, Figs. 21 and 23, and projecting sufficiently above the surface of the plate to allow for the requisite compression on the india-rubber for making a water-tight joint by the weight of the tube bearing on it, without allowing the tube to come down to a bearing upon the bed-plate L itself. A similar india-rubber bolster is carried up each side of the tube and compressed against it by oak wedges, the bolster and wedges being contained in a recess in the upright standards M M, as shown in Figs. 22 and 24. This arrangement leaves the wrought iron tube free to contract and expand longitudinally under change of temperature, without risk of leakage. The heads of all the rivets are countersunk for a short distance on each side of the bearing parts of the tube. The india-rubber bolsters are 2 inches diameter both at the bottom and sides of the tube. They are in separate pieces, the bolster under the bottom extending from the back of the wedge box M on one side to the back of the wedge box on the opposite side. The joints of the bolsters at the bottom corners are made by butting the bottom ends of the vertical bolsters upon the top of the transverse bottom bolster, the bottom ends of the vertical bolsters being slightly rounded out to fit the curvature of the bottom bolster. The side wedges are driven down tight on the ends of the bottom bolster. There are three oak wedges in each wedge box M, Fig. 24, Plate 42, with an oak feather or tongue let in to break the joints between the wedges and to guide the centre wedge while being driven down. A flat strip of india-rubber is placed between the back of the wedge box and the outermost wedge, as shown in Fig. 24. The wedges were carefully fitted before the feather grooves were made, and were put in with thick wet paint in the joints; the centre wedge was then driven down to tighten up the india-rubber bolster against the side of the tube. The spaces on either side of the wedges in the standards M are filled in with oakum and white lead.

The above construction of the iron aqueduct bridges was considered the most applicable in the first portion of the aqueduct, as no good building stone was to be obtained within any reasonable distance, and the roads were very badly suited for the carriage of materials. From the eleventh mile to the reservoir at Mugdock, however, good building stone was abundant; and all the aqueduct bridges in that district are therefore of stone. One of these, the Blairgar aqueduct bridge, is shown in Figs. 27 and 28, Plate 43, in elevation, longitudinal section, and plan; and Figs. 29 and 30, Plate 44, are transverse sections. There are in all 25 important iron and stone bridges, some of them of considerable magnitude; and about 80 distinct tunnels varying in length from 1½ mile downwards, and forming a total length of 13 miles. Where the aqueduct was formed in open cutting, the ground was filled in and the surface restored after the aqueduct was built, as shown in Fig. 15, Plate 37. At the cast iron troughs of the iron aqueduct bridges, and at the other bridges, the water way is covered with planking, as shown in the sections of the Blairgar aqueduct bridge, Plates 43 and 44, to prevent snow from choking the aqueduct. Grooves to receive stop planks are cut in the masonry of the aqueduct at intervals, and most of the bridges are provided with overflows and discharge sluices. The latter are similar in construction to the outlet sluices at the lochs, but of smaller dimensions.

The three valleys of the Duchray, the Endrick, and the Blane, Fig. 3, Plate 32, which are of great width and depth, the second being more than 2 miles wide, are passed by means of the 48 inch cast iron syphon pipes, carried down one side of the valley to the bottom, and up the opposite side. These pipes have the ordinary spigot and socket joints, a section of which is shown in Fig. 25, Plate 42, one quarter full size, the joint being made with lead N and yarn O. Some depressions on the line of these syphon pipes are crossed by flanged pipes supported upon stone piers 18 feet apart, as shown in Fig. 17, Plate 38, the joint being made by a ring of vulcanised india-rubber P, as shown by the section, Fig. 26, Plate 42, one quarter full size. In the Endrick valley two public roads and the Forth and Clyde Railway are crossed by these flanged pipes; and to support the pipes over these greater spans, cast iron brackets are put in, Fig. 17, Plate 38, abutting on the stone piers, which are thickened to receive them. The pipes are further strengthened at these places by projecting webs cast on them, as shown by the enlarged transverse section of the pipe, Fig. 20, Plate 39. It was found that the contraction and expansion of these long lengths of flange-jointed pipes under changes of temperature injuriously affected the spigot and socket lead joints at each end; and to obviate this, a felt covering about ¾ inch thick has been laid on all round the pipes, and protected from the weather by a tarpaulin cover laced tightly over the whole. This has had the effect of almost entirely obviating the inconvenience that arose from contraction and expansion.

The service reservoir at Mugdock, Plates 31 and 32, has a water surface of 60 acres, and is 50 feet deep, the top water level being 312 feet above the level of the sea. It contains 548,000,000 gallons when full, equal to a supply for 29 days at the present rate of consumption; and thus admits of repairs being made upon the line of aqueduct without interrupting the supply to the city. The reservoir is entirely artificial, being formed by two earthen embankments 400 yards and 240 yards long respectively. The water is first received from the aqueduct into a basin at the upper end of the reservoir, from which it flows over four cast iron gauge plates, 10 feet long each, brought to a thin edge, into an upper pool or compartment of the reservoir having an area of about 2 acres. The depth of water passing over the gauge plates is regularly gauged, the delivery from the aqueduct thereby computed, and the quantity of water passing every day into Glasgow is thus known. From the upper pool the water passes into the main reservoir over similar cast iron gauge plates. The water is drawn from the reservoir by pipes laid in a tunnel cut through the rock in the solid, at the end of the main embankment, no pipes being laid through the embankments themselves. At the end of the tunnel next the reservoir there is a stand-pipe with valves at different heights, which admit of water being drawn off at various levels. The water passes down the stand-pipe and along a 48 inch pipe in the tunnel for a distance of about 50 yards to a circular straining well cut in the rock. Water can also be drawn direct from the aqueduct or from the upper compartment of the reservoir into the pipes leading to the city, without passing through the reservoir, by means of a line of 48 inch pipes laid through the bottom of the reservoir from the stand-pipe back to the upper end of the reservoir where the aqueduct enters.

The straining well is shown in vertical section in Figs. 31 and 32, Plates 45 and 46; and Fig. 33 is a sectional plan. The well is 40 feet diameter and 63 feet deep, cut out of the solid rock. Within the straining well and forming an inner chamber of octagonal shape, 25 feet diameter, a series of oak frames Q Q are placed, covered with copper wire cloth of 40 meshes to the inch; these are held in the eight cast iron pillars R, which have grooves cast in them to receive the frames. These wire cloth strainers occupy only the lower part of the well, the space above being filled in with wood planking S S up to the top water level of the reservoir. The water passes from the outside through the wire cloth strainers into the inner chamber, and is taken off thence to the city by two lines of cast iron pipes 42 inches diameter, as shown by the arrows. The water undergoes no filtration, but in passing through these copper wire strainers any straws or other floating matters are separated from it. The pipes in the bottom of the straining well are provided with junctions and stop valves, as seen in the plan, Fig. 33, so as to admit of the supply being drawn direct from the reservoir while the strainers are being cleaned; which is done by emptying the well and throwing a jet of water upon the strainers from the inside outwards by a leather hose with the head pressure of the reservoir, the foul water being carried off by a tunnel through the rock. The frames Q Q carrying the strainers can also be raised to the top of the well and taken out for repairs, by being drawn up through the grooves in the cast iron pillars R in which they are fitted. The top of the straining well is roofed in and partly covered with glass, as a protection to the working gearing of the stop valves. These valves are each divided into two halves, affording together a water way of the full diameter of the 42 inch pipes. Each half of the valve is opened and shut by an iron rod passing up through a cast iron pipe, and terminating at a convenient height above the water level in a long brass nut, into which works a stationary iron screw, turned by a crank and bevil wheels.

The two lines of 42 inch pipes laid in the tunnel leading off from the straining well will deliver the whole 50 million gallons per day that the aqueduct is constructed to convey; but on emerging from the tunnel, which is 440 yards long, they are diminished to 36 inches diameter, and provision is made for additional pipes being laid when they may be required. At the point where the pipes are reduced to

36 inches diameter, a self-acting throttle valve is fixed on each line of pipes, the object of which is to shut off the water coming from the reservoir in the event of one of the pipes bursting or any other accident occurring whereby the velocity of the water in the pipe is increased beyond that to which the valves are adjusted. These self-acting throttle valves were suggested by Sir William G. Armstrong, and first used in the Manchester Water Works; and have been subsequently introduced in the Liverpool Water Works, (see Proceedings Inst. M. E., 1863, page 174.)

At intervals along the line of the mains to Glasgow and at several points in the city, stop valves are fixed in the large pipes, one of which for a 36 inch pipe is shown in Figs. 34 to 36, Plates 47 and 48. To admit of these valves being easily closed or opened, the slide is divided into two compartments T and U, one being considerably smaller than the other. The smaller slide T is the first opened, and the passage of the water through this opening so much reduces the pressure upon the larger slide U that it can also be opened with ease; the valve is thus easily worked by one man. To economise space, which is an object where large valves have to be placed in public streets, the total effective area of the valve has been reduced, in the case of these 36 inch valves, from 7 square feet, the area of the pipe, to 4½ square feet; the smaller slide T having an area of 1 square foot, and the larger U an area of 3½ square feet. To pass this contraction with the velocity that the water in the pipes will have when the discharge is greatest, the loss of head will be from 4 to 6 inches; but this loss is more than compensated for by the economy of the valve and the reduction in the dimensions of all the parts. The design of these valves is also due to Sir William G. Armstrong, and for large valves that have to be worked under great pressure they leave nothing further to be desired.

The concussion caused in large pipes by suddenly closing the stop valves requires to be guarded against, and this is done to a considerable extent by the construction of the stop valves themselves; but in order to reduce still further the risk from this cause, momentum valves are fixed on the pipes close to all the large stop valves, and behind the self-acting throttle valves. They are simply safety valves constructed on the principle of the equilibrium or double-beat Cornish valve, and have been used both in the Manchester and Liverpool Water Works, (see Proceedings Inst. M.E., 1863, page 175.) Air valves are placed upon all the summits and scouring cocks in the bottom of all the hollows on the mains. The scouring valves, as well as all the stop valves used in the city under 17 inches diameter, are the ordinary slide valves with double brass facings. The fire cocks used in Glasgow are of brass, upon the principle of the common ground cock, with the water admitted to the inside of the plug, which is hollow: the pressure of the water tends to force the plug into its seat, and thus to keep the cock tight. There are 2700 of these fire cocks in the city, placed at intervals varying from 40 to 60 yards; and also about 1200 fire cocks applied as cleansing cocks. The water meters used in Glasgow are those by Kennedy of Kilmarnock, of which there are upwards of 500 in use, producing a revenue of £15,000 a year, (see Proceedings Inst. M.E., 1856, page 151.)

For the distribution of the water supply, the north part of the city is divided into a high and a low district. The high district is supplied by the 36 inch main from the Mugdock reservoir which is brought in by Maryhill, as shown at V in Fig. 2, Plate 31; and the low district by the main W brought in by the Great Western Road. These mains as well as the subsidiary mains in the city are connected at intervals, so that an accident occurring to any one section of the mains does not to any serious extent affect the general supply to the city. The large pipes only are connected; and each distributing pipe is furnished with a stop valve where it leaves the main, and a cleansing cock at the further end.

The quantity of water sent into the city from Loch Katrine during the first six months of the present year averaged 19,100,000 gallons per day; and 3,400,000 gallons per day in addition were sent in from the Gorbals Water Works on the south side of the river. Altogether therefore the total supply to Glasgow is 22,500,000 gallons a day, and this is distributed to a population of about 485,000 persons, being upwards of 45 gallons per head per day. Of this quantity about 3½ gallons per head per day is sold by meter.

The cost of the Loch Katrine Water Works has been as follows:—

Construction of Works	£761,000	
Land, parliamentary expenses, engineering, and sundries	157,000	
		918,000
Add sums annually payable to proprietors in the two previous water companies, capitalised at 4 per cent.		674,000
Total cost of the whole Water Works . . .		£1,592,000

Rainfall in Loch Katrine district.

Situation of Rain Gauge.	Elevation above Sea.	1854.	1855.	1856.	1857.	1858.	1859.	1860.	1861.	1862.	1863.	Average Rainfall.
See Figs. 1 to 3, Plates 30 to 32.	Feet.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
At Loch Vennachar....................	275	...	...	...	...	...	...	...	72·7	69·0	61·5	67·7
At Loch Drunkie....................	420	...	...	...	...	...	...	...	71·7	78·1	73·1	74·3
At Brig of Turk	270	64·5	39·0	48·3	54·8	60·2	65·2	59·8	74·4	71·9	68·5	60·6
Between Glen Finlas and Ben Ledi	1800	61·9	56·1	...	48·3	55·2	48·0	53·8	70·4	66·0	70·7	58·9
In Glen Gyle at head of Loch Katrine	380	103·3	65·5	79·3	91·6	84·8	93·7	94·2	112·5	105·1	105·5	93·5
On top of hill above Loch Katrine tunnel	830	...	...	...	...	...	...	...	89·2	96·9	87·5	91·2
At Loch Dhu	325	...	...	...	...	...	...	...	93·2	101·1	94·7	96·3
At the inn at Aberfoyle	60	56·1	34·6	36·7	47·6	41·5	52·6	40·4	71·6	77·0	67·3	52·5
At Ledard, on hills between Loch Ard and Loch Katrine	1500	67·1	...	74·1	74·2	97·1	85·3	73·5	108·1	102·7	95·2	85·8
At head of Duchray valley, Ben Lomond	1800	109·0	69·9	81·0	85·5	90·4	91·8	88·5	99·9	114·7	117·0	94·2
At Mugdock Reservoir	320	...	...	...	...	...	...	...	...	60·6	54·8	57·7

The **President** remarked that the consumption of water in Glasgow as named in the paper, 45 gallons per head per day, appeared a very large quantity; and he enquired how much of that was supplied for public works and steam engines, &c., and how much was to be considered as the supply to dwelling houses for domestic purposes.

Mr. **Gale** replied that about 3½ gallons per head was supplied by meter for trade purposes, and about another 3½ gallons without meters for the same purposes, including steam engines, warehouses, shops, and all manufacturing and other purposes, except domestic use; making 7 gallons per head supplied for such purposes. That left 38 gallons per head as the supply to dwelling houses for domestic use, which was certainly a very large consumption, and no doubt much of it was due to waste.

Mr. E. A. **Cowper** enquired whether there were any turbines in use, driven by the water; for with the good pressure that was maintained in the mains, turbines could be used with great advantage in a large number of the manufactories of small size.

Mr. **Gale** replied that there were a few turbines of small power, but their consumption of water was included in the supply for steam engines and manufacturing purposes.

Mr. J. **Manning** enquired whether the water used for watering the streets was included in the 7 gallons that were accounted for in the manner that had been explained.

Mr. **Gale** replied that the water on the streets was included in the 7 gallons supplied for the purposes of public works.

Mr. W. E. **Newton** considered it was a question of the greatest importance to the residents in large towns, whether the water was supplied to them by meter or otherwise. In London he understood the water companies could not be induced to supply by meter, giving as one reason that there was no meter they could use which would be fair both to themselves and the consumers; and the charge for the water was therefore fixed at 5 per cent. upon the rental of the house, irrespective of the quantity used: the same was the case also in many other large towns. This did not appear a fair and proper arrangement, since a house occupying an expensive situation in the town had thus to pay much more for the water than a house on the outskirts, though the former might be using no more water or even not so much ; and he considered the only fair plan would be for each consumer to pay for the quantity actually used and no more. In Glasgow it appeared that only $3\frac{1}{2}$ gallons per head was supplied by meter out of the total daily consumption of 45 gallons, and he enquired how it was that only so small a quantity was supplied by meter, and whether the use of meters was optional with the consumers. He asked also what construction of meter was employed and how it was found to answer: if a really good meter were provided, it might be possible he thought to insist upon the water companies supplying by meter, instead of the present plan of charging irrespective of the quantity used.

Mr. **Gale** replied that the $3\frac{1}{2}$ gallons supplied by meter out of the daily consumption of 45 gallons per head was supplied to public works, and it was only for these purposes that the water was supplied by meter. Dwelling houses were not supplied by meter, but were rated according to rental, in the same manner as in London and elsewhere; and he did not see how it could be arranged for the supply of water to dwelling houses to be by meter. The meters used were Kennedy's piston meters, which he had found continued to work correctly for a great length of time, and he considered them excellent meters.

The **President** thought the water company would be glad to supply the water by meter to all consumers, if it could be so arranged, but he feared the public in general would not agree to the universal adoption of any meter. The company had frequently found it necessary to threaten that if consumers did not take better care to prevent the waste of so much water, the use of meters would have to be made general and compulsory. He certainly considered the supply by meter was the only fair plan, so that each consumer should pay for the water he actually used.

Mr. J. **Fernie** suggested that the cost of the meters would probably be a difficulty in the way of their general adoption: he enquired what would be the number required, and what was their cost.

Mr. **Gale** replied that there were upwards of 100,000 families supplied with water by the corporation within the area of distribution in Glasgow and neighbourhood, and the meters cost from £3 10*s.* to £10 each; so that the universal adoption of the meters would involve a very large outlay. In addition to this there was the further objection that one half the population of Glasgow drew their water from common taps, direct from the street main and common to twenty, thirty, or a hundred different families; and there was no means of properly apportioning the charge in such cases to the several parties.

The **President** suggested that the charge might be put upon the landlord in such cases, by a rate in proportion to the rental, the same as at present.

Mr. W. E. **Newton** observed that that was a difficulty not incidental to London and other large towns in England, because the houses were there all self-contained, and not in flats as in Glasgow.

Mr. T. **Snowdon** enquired what was the amount of the water rate in Glasgow.

Mr. **Gale** replied that the rate was at present 1*s.* 2*d.* in the pound to all the district north of the Clyde, and 1*s.* in the pound on the south side of the river.

Mr. I. **Smith** enquired what was the rate of charge for water supplied by meter to public works.

Mr. **Gale** replied that the charge by meter varied from 4·8*d.* to 7*d.* per 1000 gallons according to the quantity used, the smallest price being for a consumption exceeding 6,000,000 gallons per quarter of a year.

Mr. E. **Humphrys** thought there was not so much objection to the use of water meters in London as appeared to be felt in Glasgow. At his own house in the neighbourhood of London the water was supplied by meter from the Kent Water Works, for which the charge was 10*d.* per 1000 gallons; and he had no reason to think that he paid for either more or less than the quantity actually used.

Mr. A. **Rigg** enquired whether the piston meters that were used would allow of the water ever passing through without being registered, or whether the working parts were so accessible that the consumers might arrange them to pass the water without registering: and also whether the registration varied at all according to the pressure of water in the particular part of the town where the meter was situated.

Mr. **Gale** replied that the piston meters would allow the water to pass through occasionally without registering, when not in perfect order, which was an error in favour of the consumer; but they could not purposely be made to do so, except by damaging the meter. The registration of the piston meter was not affected by variation in the pressure of the water, but he thought meters constructed on the rotary principle would register different quantities according to the pressure.

Mr. W. E. **Newton** mentioned that a large prize had been offered by the London water companies for a really good and reliable water meter, from which it would appear they considered this still an important desideratum and were not fully satisfied with any of the present constructions of meters. One of the principal difficulties in ensuring correct registration arose he believed from the different pressures under which the meters were required to work in different situations.

Mr. E. A. **Cowper** observed that there were a great number of water meters at work in London, both piston meters and rotary meters, and he certainly thought some of them were practically reliable enough for all ordinary purposes. In a trial made about a year ago at Somerset House, with one of the piston meters and one of Siemens' rotary meters, measuring the water into a large square cast iron tank, it was found that the registration of the piston meter varied from 3 to 9 per cent. from the correct amount, according to the rate at which the water was passed through the meter; while the rotary meter varied only from 1⅛ to 1¾ per cent. under the same change of circumstances. The range of variation in rate of working which the rotary meter admitted of was especially large, and it would measure at a much slower rate than a piston meter: in fact from as little as a wineglass full per minute up to 10 gallons per minute in the smallest size of meter, and from 100 to 100,000 gallons per minute in the larger sizes.

Water companies however were not favourable he thought to putting meters in private houses, because people would not pay so much for water as at present: for where the consumers had to pay for the water by a fixed charge, such as the rate upon rental, irrespective of the quantity used, they would not hesitate to use as much water as they wanted; but if they had to pay by meter, according to the quantity used, and could save money by using less water, they would be very likely to do so, and in many cases would not use as much water as was desirable. It seemed fair to assume that the tenant of a house should use a reasonable quantity of water; and therefore what was considered to be a fair average rate was charged, which he thought was on the whole the best way.

Glasgow was greatly to be congratulated he considered on having a supply of such excellent water, containing only 2¼ grains of soluble matter per gallon; that was a most remarkable degree of purity, and was no doubt due to the almost entire absence of arable land in the drainage area from which the supply was derived, whereby the water was kept particularly free from any admixture of organic matter. The 72 square miles of drainage area was certainly a most ample extent of country for obtaining the water supply, and the storage capacity also appeared ample enough for Glasgow for the next century to come.

Mr. F. J. Bramwell enquired whether any difficulty had been experienced from the water acting upon lead pipes, on account of its exceeding purity.

Mr. Gale replied that, from careful investigations made before the water works were commenced, it was thought that under the ordinary circumstances of supply in Glasgow there would be no perceptible action upon lead pipes: and this had proved to be the case, as the water was not found to act upon lead to any perceptible or injurious extent.

Mr. H. Maudslay observed that the area of passage for the water through the stop valves in the 36 inch mains appeared to be greatly reduced as compared with the size of the pipes; and he enquired how it was that, if so large an area of passage as 7 square feet was required in the pipes, the area had been reduced to only

4½ square feet at the valves. The plan of dividing the stop valves into two parts, and opening the smaller slide first, so as to take off the pressure from the larger slide whilst that was being opened, was a simple and efficient way of getting over the difficulty of opening a large slide valve under a heavy pressure: the same object was sometimes accomplished by having a small pipe furnished with a cock, communicating with the main pipe on each side of the large valve, so as to relieve the pressure on the back of the valve at the time of opening or shutting it.

Mr. E. A. Cowper remarked that where it was desirable for the sake of convenience or economy to keep a valve small, it was reasonable to make the area of passage through the valve less than the area of the pipe: because the loss of head from the friction through a great length of pipe was very great, and therefore pipes were made as large as practicable; whereas the loss of head due to the water passing the contracted opening of the valve was but a small amount. For this reason it was a common practice to have valves or cocks smaller than the pipes connected to them.

Mr. Gale observed that there was an advantage in reducing the size of the stop valves in the mains, and so long as the area of passage was large enough to be effective, the smaller the valves were the better; since they were then more compact and more easily fixed in the streets, where the space available was often too small for fixing a large valve, on account of the street being already occupied by drains and other pipes for gas and water. In the stop valve shown in the drawings the area of passage of the 36 inch main was reduced about one third at the valve, and the loss of head in the water pressure caused by this was about 4 inches. If the contraction were in the form of a diaphragm with a hole in it, standing abruptly across the stream, the loss of head would be 6 inches; but by making the approaches to the valve slightly curved, the loss was reduced to probably not more than 4 inches of head. As the same amount of head would be lost by friction in a length of only about 50 yards of main, it was a mere trifle in comparison with the practical advantage of getting the stop valve so much smaller in size.

Mr. J. J. **Birckel** remarked that a compound slide valve, having a small slide on the back of the main slide, had been in use many years for the steam regulators of many locomotive engines, for relieving the pressure on the back of the larger slide in opening the valve, in a similar manner to the double stop-valve that had been described. He enquired what was the pressure of the water in the mains in various parts of Glasgow.

Mr. **Gale** replied that there was great variation of level in Glasgow, from the sea level to 200 feet above sea level in the higher parts of the city and 300 feet above sea level at the Mugdock reservoir; and the pressure in the mains therefore varied correspondingly, ranging from 100 lbs. per square inch down to nothing. At Clarendon Place, St. George's Road, where the two mains from Mugdock reservoir met and the distribution to the city commenced, a series of gauges were erected on the several branches, to afford the means of observing the pressure, which varied in the mains of one district from 90 lbs. per square inch in the night to 70 lbs. in the day, and in the mains of the other district from 60 lbs. during the night to 40 lbs. during the day. In both of the mains the pressure could be increased a little if desired by opening the stop valves to the widest extent.

Mr. W. E. **Newton** enquired whether the water supply was constant, night and day, to all parts of the city, or whether cisterns were used; and whether any difficulty had been experienced from frost.

Mr. **Gale** replied that the supply was constant, night and day, without cisterns, except in the higher districts where cisterns were necessary. No difficulty whatever had been experienced from frost in the large pipes in the streets, but some trouble arose occasionally with the lead service pipes in houses, where they were not properly protected from the weather. With the ordinary precaution however of having the pipes properly protected, no difficulty from frost need be feared.

Mr. J. **Fernie** observed that for crossing the three valleys of the Duchray, the Endrick, and the Blane, the cast iron syphon pipes employed were only 4 feet diameter, while the built and tunnelled portion of the aqueduct was 8 feet square; and he enquired how the pipes were connected to the aqueduct at each end.

Mr. GALE explained that the aqueduct delivered the water into a small basin of about 22½ feet by 15 feet, into which the 48 inch syphon pipe was inserted; and the other end of the pipe delivered the water into a similar basin on the other side of the valley where the aqueduct was renewed. The velocity of the water through the pipe was much greater than along the aqueduct, the fall in the aqueduct being 1 in 6336, while that between the two ends of the pipe was 1 in 1000.

The PRESIDENT enquired whether there had been any leakage at the ends of the Culegarton and similar wrought iron aqueduct bridges, where the junction of the cast iron trough with the wrought iron tube was made by the bolster of vulcanised india-rubber; and also whether there had been any trouble from freezing in the aqueduct.

Mr. GALE replied that no leakage had been experienced at the ends of the wrought iron aqueduct bridges, and the india-rubber bolster was found to make a perfectly water-tight joint, while allowing for the free expansion and contraction of the wrought iron tube. The water had never been found to freeze in the aqueduct, being covered over throughout the entire course of the aqueduct, excepting the open cast iron troughs.

Mr. J. E. SWINDELL enquired whether the geological formations met with along the line of the aqueduct from Loch Katrine to Glasgow presented a continuous and complete series according to the regular order.

Mr. GALE exhibited a series of specimens of the rocks passed through in the construction of the aqueduct. He explained that the Loch Katrine tunnel commenced in the lowest of the sedimentary rocks, after which came the mica schist and the clay slate. There was then a gap in the geological series at the commencement of the Clashmore tunnel, which passed through the conglomerate and the old red sandstone, and the red sandstone series was complete to the upper end, where it was thrown out by a great belt of amygdaloidal trap at the Mugdock tunnel, causing a void; and then the coal measures were met with at once, extending all the rest of the way to Glasgow.

The PRESIDENT enquired how rapidly the water level in Loch Katrine rose after a heavy rainfall.

Mr. GALE said he had known the water level rise as much as 12 inches in 24 hours when there had been a heavy fall of rain.

The PRESIDENT enquired what was the pressure at the lowest part of the 48 inch syphon pipes crossing the valleys.

Mr. GALE replied that the greatest pressure in the 48 inch pipes was 240 feet head, at the bottom of the Endrick valley, and that was the greatest pressure at any part of the course of the works.

Mr. A. RIGG asked what provision was made in the event of an accident, such as the bursting of one of the 48 inch pipes.

Mr. GALE said there were men constantly stationed for the purpose of shutting the water off in case of any accident, by means of sluice valves fixed at the aqueduct bridges, the water being discharged into the streams below, until orders could be sent to shut off the water at the Loch Katrine inlet.

The PRESIDENT enquired how often the straining well at Mugdock required cleaning, and whether much refuse was found in it at the time of cleaning.

Mr. GALE replied that the straining well was cleaned about once a week during summer and once a fortnight during winter. The refuse found upon the strainers consisted of leaves and bits of sticks and straws, and was sufficient to prevent the action of the strainers if allowed to go on longer, as the strainers were very fine and close, being made of copper wire cloth with 40 meshes to the inch.

The PRESIDENT proposed a vote of thanks to Mr. Gale for his paper, which was passed.

The following paper, by Mr. Andrew Duncan of Glasgow, Resident Engineer to the Clyde Trust, communicated through the President, was then read:—

ON THE CONSTRUCTION AND RESULTS OF WORKING OF THE LARGE STEAM DREDGERS ON THE CLYDE.

By Mr. ANDREW DUNCAN, of Glasgow.

The improvements in the channel of the river Clyde were commenced in 1770, under the direction of Mr. Goulbourne of Chester. At that time the navigable depth to Glasgow was only 3 feet at high water spring tides, as shown in the diagram, Fig. 7, Plate 52, with 1½ feet at low water; while the high water of neap tides did not reach Glasgow at all. The river was crossed by seven fords, one being as far down the river as Dumbuck, about 12 miles below Glasgow, which had only 2 feet depth over it at low water. The first operation seems to have been the removal of the Dumbuck ford; and numerous cross jetties were afterwards shot out from either bank as far up as Glasgow, for the purpose of narrowing the channel, their outer ends being subsequently connected by parallel dykes. Soon after 1798 a few ploughs and a dredging machine worked by manual labour were employed in deepening the shallowest places; and the result of these operations was to enable vessels drawing 6 feet of water to come up to Glasgow at high water spring tides.

By the introduction of Steam Dredgers upon the Clyde, very important improvements have been effected in enlarging the channel of the river. In 1824 the first steam dredging machine was obtained, which now belongs to the town of Dumbarton, and is at work on the river Leven running out from the foot of Loch Lomond into the Clyde. By that time the Liverpool traders were coming up to Glasgow at high water spring tides, drawing 11 feet of water, as shown in the diagram, Fig. 8, Plate 52. In 1831, there were two vessels drawing 13 feet; in 1836, six vessels drawing 15 feet; in 1839, one drawing 17 feet; in 1853, two drawing 19 feet; in 1860, eight drawing 19 feet; and in 1863, two vessels drawing 21 feet arrived at Glasgow, illustrated by the diagram, Fig. 9, Plate 52. The register tonnage of the vessels arriving and departing from Glasgow now exceeds three millions annually; and the minimum depth of the river is now not less than 12 feet at low water, with a rise of 9 feet at average spring tides and 7 feet at neap tides. The deepening and widening of the channel is still in progress, and more powerful machinery is in course of construction in order to hasten on the work. The depth which is now contemplated throughout the whole length of the river up to Glasgow is 15 feet at low water, giving 24 feet depth of high water at spring tides and 22 feet at neap tides.

As regards the deposit to be removed from the river bed, the greater portion of it comes from the drainage of the city, all the sewers of which discharge into the harbour, where the deposit lodges: also a considerable quantity of sand is brought down from the upper reaches of the river by the land floods, and lodges chiefly above Glasgow bridge. One of the two large double dredging machines is kept constantly at work in the harbour, the maintenance of which costs about £11,000 annually, and three fourths of this amount may be said to be due to city sewage.

The entire dredging plant of the river consists of two large double dredgers, shown in Plates 49 to 51, and three single dredgers, making five in all: connected with which there are 350 punts, each capable of carrying 8 cubic yards or 10 tons of material; one tug-steamer of 80 horse power; and four screw hopper barges, each capable of carrying 300 tons, shown in Plates 54 and 55. During the last twenty years, 8,114,872 cubic yards or 10,143,590 tons of material have been removed by dredging; last year's work, ending June 1864, being 632,272 cubic yards or 790,340 tons.

The following is a general description of the two large double dredgers, Nos. 1 and 6, the latter of which is shown in Plates 49, 50, and 51.

The first double dredger, No. 1, was constructed in 1851 by Messrs. Murdoch Aitken and Co. of Glasgow. The hull is of iron, 98½ feet long, 31 feet broad, and 10 feet deep, drawing 5 feet of water. The engine is a direct-acting marine engine, with cylinder 37 inches diameter and 3 feet stroke, and makes about 33 revolutions per minute. The boiler is a flue boiler with four furnaces, worked at a pressure of 4 lbs. above the atmosphere, and burning about 44 cwts. of coal per day of 10 hours. The bucket frames are of timber, trussed with iron rods, and the buckets can dredge in 22½ feet depth of water. The buckets are 38 in number in each well, and each contains when quite full 3½ cubic feet. The motion is communicated from the engine to the upper tumbler by cast iron shafting. The tumbler makes about 6½ turns per minute, or 13 buckets per minute; but as the buckets are never quite full, the quantity lifted when working in good material is about 10 tons in 4 minutes, or about 2 cubic feet per bucket. Taking the year ending June 1864, the total quantity of material lifted by this dredger was 143,360 cubic yards or 179,200 tons; and as the total number of engine hours was 2483, the average quantity lifted per day of 10 hours was about 720 tons.

The material is discharged over the stern of this dredger, which arrangement was preferred to discharging at the sides inasmuch as less room is occupied in filling the punts by discharging over the stern; but this plan has the disadvantage of causing a loss of time while the punts are being shifted after each has been filled. Another disadvantage is that when working during flood tide in the lower reaches of the river, where the current is much stronger than in the harbour, the punts become nearly unmanageable, the current forcing them so hard against the stern of the dredger, which is always moored with its bow up-stream, as to render the shifting of the punts when filled a work of considerable labour; so much so in fact that working on the flood tide in the lower reaches of the river was avoided as much as possible.

The cost of this dredger was £8500. The crew required to work the dredger and punts consists of eighteen in all, namely:— captain, mate, engineer, fireman, bow craneman, sternman, wellman, two deckhands, cook, watchman, and seven men connected with the punts. The expenses of working during the year ending 30th June 1863 were:—

	£	s.	d.
Wages	£916	19	2
Coals	204	10	7
Stores	73	11	5
Total working expenses	£1195	1	2

and the average annual cost of repairs is about £580.

The other large double dredger, No. 6, shown in Plates 49 to 51, was constructed in 1855 by Messrs. Thomas Wingate and Co. of Glasgow; and is arranged so as to discharge over the sides, in order to obviate the complaints brought against the previous dredger when working in the lower reaches of the river, for which this one was principally intended and is generally used. The crew required to work this dredger, exclusive of the crews on board the screw hopper barges, is twelve in all, namely:—captain, engineer, fireman, mate, cook, watchman, and six deckhands. Previous to the hopper barges being substituted for the small punts, this machine required a crew of twenty-one. The expenses of working during the year ending June 1863, the hopper barges being used, amounted to:—

	£	s.	d.
Wages	£562	1	4
Coals	171	1	6
Stores	95	4	6
Total working expenses	£828	7	4

The annual average cost of repairs is about £980, being considerably more than in the case of No. 1 dredger; for as the latter is working in soft soapy sludge, the buckets and links do not get cut up so soon as if working in sand, as in the case of No. 6.

Fig. 1, Plate 49, is a longitudinal section of No. 6 Dredger; and Fig. 2, Plate 50, a plan, showing the line of punts on each side of the dredger. Fig. 3, Plate 51, is a transverse section to a larger scale.

The dredger is built entirely of iron, and is 120 feet long and 33 feet broad, with a flat bottom and 5 feet draft of water; the plates are 7-16ths inch thick at the bottom and 5-16ths inch at the sides. The two boilers A A, Figs. 1 and 3, Plates 49 and 51, fixed in the centre of the vessel, are low pressure cylindrical flue boilers, 6 feet diameter and 15 feet long, working at 3 lbs. pressure above the atmosphere; and the coal consumed is about $2\frac{1}{2}$ tons per day of 10 hours. The engine B is a single side-lever condensing engine, with 37 inch cylinder and 3 feet stroke, running at an average speed of about 32 revolutions per minute, and driving the tumbler shafts C C of the two bucket frames D D at the reduced speed of 6 revolutions per minute, by two sets of spur gearing consisting of mortice wheels and cast iron pinions. Either set of buckets can be stopped and started independently of the other by means of clutch boxes worked by levers upon deck.

The power is communicated to the tumbler shafts C C through friction wheels E E, which are adjusted so as to transmit only a definite amount of power, and to slip round freely whenever the resistance exceeds that limit, from the buckets cutting too deeply into the ground or meeting with any obstacle: by this means any risk of damage to the machinery is prevented. One of these friction wheels is shown enlarged in Figs. 4 and 5, Plate 52. It consists of one ring revolving within another, the inner one F being keyed upon the shaft, and having a cylindrical recess of rectangular section turned in the circumference, $8\frac{1}{2}$ inches wide and 1 inch deep, in which fit a series of cast iron segment blocks I I. These are held in recesses in the outer ring G, and are each pressed against the inner ring by a set screw, adjusted to give the required amount of friction for driving the inner ring F and the gearing connected with it.

The bucket frames or dredging ladders D D, Plates 49 and 51, consist each of a pair of wrought iron plate girders, 77 feet long and 3 feet 9 inches deep in the centre, fixed parallel to each other with 2 feet 3 inches space between them, and stayed together by transverse plate stays. A transverse section of one of the bucket frames is shown in Fig. 6, Plate 52. These frames carry a series of cast iron rollers, upon which the bucket links travel; and a cast iron tumbler C and H, Fig. 1, at the top and bottom ends, over which the links work. Each ladder is suspended at the upper end by cast iron dead-eyes, firmly bolted to the main framing of the dredger; through these dead-eyes the upper tumbler shaft C passes freely, and round them the ladder turns in being lifted or lowered: thus the upper tumbler shaft C does not bear any part of the weight of the ladder D. The shaft C is of wrought iron, and works in top and bottom brass bushes in pillow blocks bolted to the main framing of the dredger. Each ladder works in a vertical well K, Figs. 2 and 3, passing through the bottom of the vessel.

There are 41 buckets to each ladder, one of which is shown separately in Plate 53; Fig. 10 is a vertical section, Fig. 11 a plan of the back, and Figs. 12 and 13 transverse sections at the mouth and at the bottom. The buckets are constructed of 5-16ths inch wrought iron plates, bent and rivetted, with a flat back ½ inch thick, upon which four wrought iron bars J J are rivetted, having eyes at the ends. These are connected together by the two intermediate links L L, 3 inches square, and jointed with 2¼ inch steeled pins, the whole forming a continuous chain with 2 feet pitch of the links. The pins are prevented from turning in the eyes of the bucket links J, which are not steeled, and the eyes of the intermediate links L are bushed with steel on the wearing side. In another dredger, No. 7, which is the most recent construction, the plan is adopted of inserting a bush of hard steel 5-8ths inch thick into the eyes of the single links L, while they are hot; and when worn this bush is driven out and another inserted, so that the eyes of the links do not wear at all. The mouth of the bucket is made 1¼ inch thick at the point, tapered to ½ inch at the sides, and is faced on the outside with steel ½ inch thick welded on the plate, as shown by the darker section in Figs. 10 and 12; the mouth is shaped in a projecting scoop form, for excavating and lifting the material dredged, as each bucket in succession passes under the bottom tumbler H of the ladder, Figs. 1 and 3.

The depth of excavation of the buckets is regulated by the lifting chain M, Fig. 1, Plate 49, attached to the lower end of the bucket frame D, and hoisted at the rate of about 26 feet per minute by the windlass or hoisting barrel N, which is driven by a small shaft from the engine through a clutch box and friction wheel, similar to those giving motion to the buckets and also worked by a lever upon deck. The depth of dredging is continually gauged during work by a man stationed at the bucket well K holding a gauging rod resting on the river bottom, and having the lifting lever at hand and also a break handle for lowering the bucket frame, so as to keep the buckets constantly adjusted to a uniform depth of cut, according to the surface of the ground. A self-indicating gauge has also been fitted up on deck, so that the captain by glancing at the position of the bucket frame may in an instant tell at what depth below the surface of the water the points of the buckets are working. The greatest depth the dredger can work at is about 28 feet.

The forward motion for the cutting of the buckets is given by the bow chain O, Plates 49 and 50, which is 1 inch diameter, attached to a single-fluked anchor weighing 12 cwts. placed about 600 feet ahead of the dredger when at the commencement of a cut. The chain is hauled in with a slow motion by the windlass P, driven by a second small shaft from the engine through a clutch box and friction wheel, and having a set of change wheels for the purpose of regulating the rate of advance according to the nature of the material that is being excavated. This rate of advance varies from about 4½ feet per minute in soft sand to 1½ feet per minute in hard material. The dredging is done in parallel cuts of about 120 feet length. A corresponding windlass with two mooring chains R at the stern of the vessel gives the means of drawing back the dredger to commence a second line of excavation parallel to the former one; this windlass is driven by a small high pressure donkey engine with a pair of 12 inch cylinders, the dredging engine and machinery standing still during the time occupied in going astern, which is about 15 minutes, the speed being about 8 feet per minute. The two side warp lines S S, Fig. 2, extending from each side of the dredger, serve to steady it constantly during the progress of each cut, and to shift its position into the new line of excavation; they are worked by the surging heads T T, driven by the engine, or by hand power when required. The kedge anchors for these side warps are placed forwards of the dredger, so that the warp lines shall be somewhat in the position shown in the plan, Fig. 2, when the dredger is at the commencement of a cut; the warps are also passed round leading blocks when required, since it is desirable they should be as nearly at right angles to the dredger as possible. The two warps on the side next the sailing channel of the river are lowered or slacked out when any vessel is passing, but are immediately tightened up again when the vessel has passed.

This dredger, No. 6, has now been at work for nine years, and has not required any repairs excepting for the wear and tear of the buckets, links, and rollers, and the usual repairs on the hull, &c. The upper tumbler however, having been found too low to allow of the shoot being placed at a sufficient height and slope for loading the large screw hopper barges, was raised 2½ feet higher. The steeled mouths of the buckets last for the year's work of about nine months, when the buckets require to be thoroughly overhauled and put in repair. The pins and links of the bucket chains last generally about four months, and are replaced from time to time as required; a supply of duplicates being kept ready on board for the purpose. The rollers over which the buckets travel in ascending the dredging ladder are of cast iron, 1 inch thick in the barrel, with wrought iron spindles, having 1⅜ inch journals laid with steel, which lasts about three months before being worn out; these run in small cast iron steps with hard wood caps, fixed on the top flange of the ladder, which are readily renewed when worn out, the cast iron bush lasting about two months, and the wood cap about nine months. Each bucket weighs 5¼ cwts., and the total weight of each set of buckets and links is about 7¼ cwts. The cubic content of each bucket is 3¾ cubic feet, and the average quantity of material brought up by each when working in sand is about 2 cubic feet. The number of buckets discharged per minute is 13 to 14 at the regular speed of about 6½ revolutions per minute of the tumbler shaft.

The total quantity of material raised per day of 10 working hours varies very much according to the nature of the material dredged. Where the dredger No. 6 is at present working, about 1¼ mile below the river Leven, the rate of working is 150 tons per hour of the engine; while in hard ground the quantity may perhaps be only one half of this. Taking the entire work performed by this machine during last year, namely 303,957 tons in 2680 engine hours, the average work for a day of 10 engine hours is 1134 tons, or 113½ tons per hour. The total quantity of material lifted by the two large dredging machines Nos. 1 and 6 during the year ending 30th June 1864 amounts to 386,752 cubic yards, of which about 250,000 cubic yards may be considered as due to maintenance, and the remainder to the permanent widening and deepening of the channel.

The cost of dredging per cubic yard, taking the year ending 30th June 1863, as performed by No. 1 dredger, was as follows, the dredged material being conveyed away by the punts:—

Wages, coals, stores, repairs, and 5 per cent. interest	3·02	pence.
Repairs of punts	1·59	„
Towing punts to and from place of deposit	2·28	„
Discharging punts by wagons	12·29	„
Total cost of dredging per cubic yard . . .	19·18	„

The cost of dredging as performed by No. 6 dredger during the same period, with the screw hopper barges for carrying away the material, was as follows:—

Wages, coals, stores, repairs, and 5 per cent. interest	4·06	pence.
Discharging by hopper barges— Wages, coals, stores, repairs, and interest . . .	2·30	„
Total cost of dredging per cubic yard . . .	6·36	„

During this year No. 6 dredger was working near the two extreme ends of the river; and as during one half of the time it was attended by only two hopper barges in place of four, for discharging the material, much time was necessarily lost. This has since been rectified by the construction of additional barges.

The dredged material is disposed of according to two different modes. That filled into the 10 ton punts is towed down to some convenient part of the river, and discharged by barrows or wagons on to the banks or fields adjoining. That put into the screw hopper barges, shown in Plates 54 and 55, is carried down to Loch Long, beyond the mouth of the Clyde, and deposited by opening the hopper doors U at the bottom of the carrying space W, as shown by the dotted lines in Plate 55. At the place where the deposit is made, the water is upwards of 200 feet deep, and the mouth of the loch is about 27 miles below Glasgow; the hopper barges at present at work contain each 300 tons of dredgings, and steam from 8 to 9 miles per hour. This latter mode is by far the most economical way of disposing of the dredged material, as seen by the above statement of the cost by the two methods; and the result has been so satisfactory that two additional barges are now being constructed, each to be capable of carrying 400 tons, making six barges in all. Fig. 15, Plate 55, shows the hopper barge being filled by the spout V from the dredger.

In conclusion it may be mentioned that a larger and more powerful single dredger, shown by the accompanying model, is now being constructed for the Clyde Trust by Messrs. A. and J. Inglis, of Glasgow. The dimensions of this dredger will be: extreme length 157 feet, extreme breadth 29 feet, depth 10 feet 9 inches, and bucket frame capable of working in upwards of 30 feet depth of water. The engine will be horizontal, with cylinder 44 inches diameter and adapted for a 3 feet stroke: the boiler will be tubular and capable of working to 25 lbs. pressure per square inch above the atmosphere. The buckets will be 39 in number, discharging over the side; the pitch of the bucket chain will be 30 inches, and each bucket when quite full will contain 13½ cubic feet. The flat bucket back with the double links will be made of malleable cast iron with the links cast solid upon it: this construction has been found to last without requiring repair for more than double the time of the ordinary backs with rivetted links, shown in Plate 53. The bucket rollers will not require spindles, as they will have necks cast on the ends of the rollers, which will answer for the spindles. The lower tumbler shaft will be of wrought iron having strong rings or hoops at the journals, so that when worn the hoops can be easily removed and replaced. The only other difference of any consequence from the present dredgers will be in using grooved frictional gearing for driving the hoisting barrel that lifts the dredging ladder, instead of spur gearing with a friction wheel as previously described. The total cost of the dredger will be about £17,000, and it is expected to be ready early in March next.

Specimens were exhibited of the dredger buckets and links, and the bucket rollers and bearings, &c., both new and worn out, together with samples of the material raised in dredging; and also models of the dredger and of the screw hopper barge.

Mr. W. SIMONS said he had built the screw hopper barges that were used in connection with the Clyde dredgers, and it was only within the last two years that they had been adopted: previously 350 of the square punts had been required to carry away the dredged material, but four of the barges now did the work of the 120 punts formerly attending one dredger. Each barge carried 300 tons, and was 120 feet long, 24 feet beam, and drew 8½ feet of water when loaded; the engine was 40 horse power with 21 inches stroke, driving a screw 7 feet diameter, and the speed was the same whether loaded or empty, amounting to 9 miles per hour. The Clyde trustees contemplated abolishing the old punts altogether and employing only the screw hopper barges for removing the material dredged. The barges were loaded in about 70 minutes, and ran down the river and up Loch Long to a distance of about 50 miles from Glasgow, where the whole of the dredged material was discharged through the flap doors in the bottom. Hydraulic gearing was used to close and open the bottom flap doors in two of the barges, and in the others a common windlass had been applied, which had been found to work better. The total expenses of working the dredgers and barges were about £2 5*s.* per day, including wages, fuel, oil, and tallow; and the result of employing the screw hopper barges had been to reduce the cost of dredging from about 1*s.* per ton of material when the punts were used to only *4d.* per ton with the barges, making a saving of between £19,000 and £20,000 per annum.

By this system of dredging it might indeed be possible, he thought, to form an inland town into a seaport, such as Preston, Lancaster, Manchester, or Paris, where there was already an outlet into the sea for carrying away the dredged material; all that was required would be dredgers and barges of sufficient power and capacity for the quantity of work to be done, since the double dredgers now at work in the Clyde raised each about 1100 tons per day in regular continuous work, as stated in the paper. About the year 1800, when the depth of the river at Glasgow was only about 3 feet at high water, the annual revenue from ships coming up the Clyde was only £3320; but in 1825, when the river had been deepened by dredging to 12 feet, allowing vessels of 300 tons burthen to come up, the revenue had increased to £9000; while in 1863, with the depth increased to 22 feet at high water, the revenue amounted to £118,000, and the river was deep enough to float the "Black Prince" armour-plated frigate of 6000 tons burthen, built by the President, the largest ship that had yet been launched in the Clyde.

The PRESIDENT enquired how long it took to discharge the hopper barges through the bottom flap doors, and how the doors were arranged to be opened.

Mr. W. SIMONS replied that only 4 or 5 minutes were required to discharge the whole 300 or 320 tons of material carried by the hopper barge. There were twelve doors or six pair at the bottom, hinged to the iron hopper, and lined inside with timber; and the doors were let down for discharging by releasing the chains that held them up while the hopper was full. The chains passed over pulleys in the longitudinal iron girder which extended over the hopper from end to end.

The PRESIDENT enquired what part of Loch Long the material was deposited in.

Mr. W. SIMONS said the barges were not confined to Loch Long in particular for depositing the material, but might go to a greater distance from Glasgow if necessary. Loch Long had been chosen because it was the deepest part of the channel near Glasgow, the depth being about 200 feet over a considerable portion of the loch, and the material could be deposited at any part of the loch.

Mr. W. E. Newton remarked that a dredging machine on a different principle had been used very successfully in different parts of the United States for many years, consisting of a large bucket fixed at the end of a long lever worked by chains; the bucket was lowered and dragged along the river bottom to fill it, and was then lifted by the lever, and swung round horizontally to the required position for discharging the stuff, which was let fall through a door in the bottom of the bucket into the barge beneath. The bucket raised about 26 cubic feet of soil at each stroke on an average. That appeared to him a simpler contrivance than the dredging machines ordinarily used in this country, such as those described in the present paper; it was at any rate much less expensive, and allowed of swinging the bucket round into any position required for discharging into the barge, whereas with the ordinary dredging machines the barge had to be brought to a particular place for receiving the stuff from the spout of the dredger. The gearing for working the lever was driven by a self-acting friction clutch somewhat similar to that described in the paper, except that in the American machine the inner or driving pulley was surrounded by a bridle provided with friction blocks, which were tightened against the pulley when running forwards, but slackened in running backwards; so that the clutch simply held on in working, and was not limited to slip when the resistance exceeded a certain amount, but would transmit the whole power of the driving machinery, its only purpose being to avoid breakage from sudden jerks and to release itself for running backwards. He had seen a machine on that principle, known as the "American excavator," used experimentally some years ago on the Eastern Counties Railway in the neighbourhood of Brentwood, for excavating a cutting, and all the gearing in it was worked with friction clutches of the same kind. That description of clutch was indeed much used in America for all sorts of machinery, and was found very economical and effective in preventing breakages, by allowing the gearing to yield under any undue strain. He had never known it fail in transmitting the full driving power, and thought it would have some advantage over the friction wheel described in the paper.

Mr. H. **Maudslay** enquired whether the friction wheel in the dredger described in the paper was found effectual in work, by always slipping whenever the buckets came into too hard ground or took too deep a scoop into the soil, or met with any other obstruction.

The **Secretary** said he had seen the dredger at work in the Clyde, and the friction wheel was found to answer its purpose thoroughly. The screws of the friction blocks were adjusted originally to the pressure required for the ordinary working, and then continued unaltered, without requiring any further attention in working. He had seen the bucket frame lowered slightly below the proper working position, causing the buckets to bite gradually deeper in the bed of the river, until the resistance was just sufficient to overcome the friction of the blocks, when the buckets stopped while the driving pulley or ring continued to revolve outside the friction wheel; but on slowly raising the bucket frame again, the friction wheel gradually started again as the resistance diminished, and the whole worked with complete smoothness and readiness. The engineer working the dredger stated that the friction wheel had given no trouble, and there had not been any difficulty in keeping it adjusted exactly to the point desired for working. The same kind of friction clutch was also applied to the lifting gearing by which the end of the bucket frame was raised and lowered; so that all portions of the machinery were started and stopped quite gradually, the friction gear being continually called into action to meet the irregularities in the level and material of the bed of the river and prevent any straining of the machinery.

Mr. J. **Shepherd** asked whether the material raised by the dredgers was used for agricultural purposes, as a manure, and whether it had any commercial value for such purposes, since it appeared the sewage of Glasgow was all discharged into the Clyde and would therefore be deposited in the bed of the river.

The PRESIDENT replied that the quantity of sewage matter deposited in the river bed formed so very small a proportion of the quantity of material raised by the dredgers, that it had never been thought to apply it as a manure, and it had no commercial value for such a purpose.

In reference to the American dredger that had been referred to, a somewhat similar apparatus was occasionally used on the Clyde at the present time in dredging alongside the wharfs in the harbour, consisting of a rake or plough fixed on the end of a long pole, which was worked from the bank by a number of men, or from a punt on the river, and was moved along the edge of the wharfs for clearing out the material from the face of the quay and removing it within reach of the dredger, in cases where the dredger could not be conveniently worked close alongside.

Mr. J. J. BIRCKEL observed that the depth of 13 feet at low water in the Clyde at Glasgow and 22 feet at high water would give a tidal fall of only 9 feet; and he enquired whether that was the actual tidal fall at Glasgow, since at Liverpool, on the same coast, the tidal fall was as much as 32 feet. He asked also whether there was not a risk of some portion of the material deposited in Loch Long being brought back into the river by the tides, as the loch was so close to the mouth of the Clyde: in the case of the Mersey no deposit was allowed to be made at any part of the approaches to the river, for fear of interfering with the channel.

The PRESIDENT explained that there were so many arms of the sea to fill near the mouth of the Clyde, and so many bends in the river itself, that the tidal wave did not come up to Glasgow in the same quantity as in the Mersey; and the rise and fall at Glasgow averaged therefore from 7 to 9 feet only, very seldom more. Loch Long was a blind arm of the sea, with no outlet at the further end, and no navigation through it, and there was very little tide in it: and as it was about 200 feet deep where the barges were discharged, there did not appear any probability of any portion of the deposit being carried back by the tide.

From the paper that had been read it was obvious that the dredging machines employed in the Clyde had been productive of very remarkable advantages to Glasgow. From a depth of water of only about 3 feet at the beginning of the present century, the river bed had now been deepened to about 22 feet at Glasgow at high water within the space of about 63 years. But it was since the introduction of steam navigation into the Clyde that the greatest part of this improvement had taken place. The steam tugs drawing vessels up and down the river first led to the rapid deepening of the bed by dredging; and then the increase of revenue arising from the larger burthen of the vessels trading to Glasgow afforded the means of increased expenditure upon the dredging operations: thus both the depth of the river and the advantages to the city went on increasing simultaneously.

He moved a vote of thanks to Mr. Duncan for his paper, which was passed.

The following paper was then read:—

ON THE WORKING AND CAPACITY OF BLAST FURNACES.

By Mr. CHARLES COCHRANE, of Dudley.

At a former meeting of this Institution in 1860 the writer read a paper on a method of taking off the gas from a close-topped blast furnace at the Ormesby Iron Works, Middlesbrough (see Proceedings Inst. M. E., 1860, page 121); and the original construction of closed top and lifting valve for charging is shown in the accompanying Fig. 1, Plate 56, the materials for the charges being filled into the exterior space B surrounding the charging valve A, which is drawn up into the position shown by the dotted lines for allowing the materials to fall into the furnace; while the gas is taken off from the furnace top by the passage E.

The usual plan of closed top adopted in blast furnaces is that represented in Fig. 3, Plate 58, in which it will be seen that the materials are filled in against a lowering cone C, placed in the throat of the furnace, which on being lowered into the position shown dotted permits their fall into the furnace. The tendency of the material in this case is to roll outwards from the charging cone to the side of the furnace, and thence back again to the centre, as shown in the drawing.

It was thought at the time of adopting the plan shown in Fig. 1, Plate 56, that the height of the materials carried by the same furnace would be increased, and that a corresponding economy in consumption of fuel would result, owing to the circumstance that where the plan shown in Fig. 3 is adopted the level of the materials must always be maintained at a certain distance below the top, to ensure the fall of the cone C at charging time. The plan shown in Fig. 1 was devised with due regard, as it was thought, to the arrangement of the materials in the furnace; and it was intended that they should arrange themselves as shown by the dotted line in that drawing, part of the larger material rolling to the outside of the furnace and part to the centre.

As long as the furnace could be kept so full as to ensure the arrangement of materials shown by the dotted line in Fig. 1, there was no reason that it should not work uniformly; but the practical result was that it was found impossible to keep the furnace sufficiently full to secure the distribution of the materials in the manner intended. The level of the surface of the materials was generally below that intended, the consequence of which was that the material on falling into the furnace was shot into the centre, from whence the largest pieces rolled outwards, and the whole charge arranged itself as shown by the full line in Fig. 1. The result of this was irregular working of the furnace over a period of many months, during which an explanation of the irregularity was in vain sought for. At one time it was thought the back pressure of the escaping gas had something to do with the irregularity; at another the cause was sought for in the difficulty of keeping the hopper valve A of the furnace tight, and the necessity for using small material around the valve as a kind of lute between every charge to prevent the escape of the gas: until it occurred to the writer that the arrangement of the materials in the furnace was the sole explanation of the difficulty, and that as all the material was shot into the centre of the furnace the small pieces would remain there whilst the large would roll to the outside. Believing that it was of great importance, in order to secure uniform results, that there should be a uniform distribution of the heated gas from the hearth over the entire horizontal area of the furnace at each stage of its height, he considered that the effect of any small material being collected in any portion of the area would be to obstruct the passage of the gas at that part, and so prevent that portion of the material from being heated to its proper degree of temperature.

Deeming this to be the explanation of the irregularities experienced in the working of the furnace, the writer devised a method of distributing the material so as to prevent such a result, by the introduction of a frustum of a cone D, Fig. 2, Plate 57, suspended inside the throat of the furnace, which was found to be all that was necessary. The materials then arranged themselves in the desired manner, as shown in the drawing; and the result has since been a perfect uniformity in the working of the furnace. Where previously a yield of foundry iron from the same furnace could not be relied upon for more than about 24 hours at a time, and the annoyance was incurred of the furnace suddenly changing to white iron, the production of white iron except when desired is now unknown. A consideration of these facts will lead to a fair estimate of the importance of the arrangement of the materials in a blast furnace. Anything that opposes the free passage of the ascending heated gas at any part of the furnace must direct the gas into another channel, and the material thus left insufficiently acted upon finds its way into the hearth at a low temperature, and white iron is the result.

The effect produced on the distribution of material by this internal frustum of a cone is obviously similar to that of the ordinary lowering cone when lowered, shown in Fig. 3, Plate 58; and the latter has now consequently been finally adopted at the Ormesby Iron Works as the permanent form of the arrangement, and is now being carried out there.

The most perfect action of a blast furnace the writer conceives to consist in the development of the highest temperature needed for the production of the required quality of iron, in a layer or stratum as little removed from the tuyeres as possible; and the gradual absorption of the heat from the ascending gas by the materials through which it passes, until it leaves the throat of the furnace at the lowest possible temperature. Anything which tends to cause a more perfect absorption of the heat developed in the hearth, or to lower the level of the region of highest temperature in the furnace, will thus be beneficial.

With regard to the absorption of the heat from the gas, it is obvious that the hotter the temperature at which the gas escapes, the more wasteful must be the effect; and theoretically the height of a furnace should be increased until the temperature of the escaping gas is reduced to that of the materials on their introduction into the furnace top. This is the theoretical limit to the height of a blast furnace: but it must not be forgotten that the less the difference in temperature between two bodies, the less rapid is the communication of heat from the hotter to the cooler; hence for the absorption of the last few degrees of temperature from the ascending gas a much greater height of material is necessary than where the gas and the material differ more widely in temperature. Already with 50 to 60 feet height of blast furnace in the Middlesbrough district the temperature of the escaping gas does not exceed 500° to 600° Fahr.; and it is a question to be answered only by experiment how far the gain from the heights of 70 to 75 feet already accomplished at Middlesbrough, and further heights of 10 or 20 feet additional that are contemplated, will compensate for the extra work in raising the materials to the additional height and for the more substantial plant required. In the direction of height there is unquestionably on this account a limit which will speedily be attained; supposing the limit be not previously determined by the necessity for increased pressure of blast and by the increased difficulty in working the furnaces.

As regards the benefit produced in the working of a furnace by lowering the level of the region of highest temperature, it is evident that this benefit is of the same nature as in the previous case, since the lowering of that level is equivalent to an increase in the height of the furnace. The level of the region of highest temperature is dependent upon the heat of the blast, and is brought down nearer to the tuyeres only by using a hotter blast: and in the writer's opinion the chief source of economy yet to be attained in the working of blast furnaces, independent of the more extended application of the waste gas, lies in the use of blast heated to a still higher temperature than that hitherto known. The yield of iron from any ironstone is governed by the percentage of iron it contains, and the consumption of limestone by the nature of the ironstone: and both these are therefore fixed quantities for the special materials employed. But that is not the case with the coke, which offers a fruitful source of saving; and in what way therefore this saving is effected by increased temperature of the blast becomes a most important question, involving as it does the general theory of hot blast.

It appears to the writer that in order to explain the effect of the hot blast it is necessary to regard the nitrogen of the atmosphere and the generated carbonic oxide as the great heat "carriers" in the operations of the blast furnace. This consideration involves two others: namely the time required for heating the nitrogen from its initial temperature at entering the furnace up to that needed for the fusion of the materials in the furnace; and also the method by which the gases are heated. Taking it for granted that the colder and consequently the denser pure oxygen is the more intense is the combustion of any body burning in it, there is evidently no necessity for heating this constituent of the atmosphere. It is further obvious that supposing 3000° Fahr. be the temperature required for the fusion of the materials on their reaching the hearth, then every pound of the nitrogen introduced by the blast must be raised to that temperature before the fusion can take place.

Now in a cold-blast furnace the nitrogen is introduced at the lowest temperature, and requires necessarily the longest time for being raised to the requisite temperature: hence the maximum temperature in the furnace is produced at a higher level, and diffused over a larger portion of the furnace where it is not wanted; and it is consequently impossible in some cases ever to get the temperature sufficiently high at any part of the furnace to produce more than the qualities of iron known as forge iron. In proof of this may be mentioned an attempt made some years ago at the Ormesby Iron Works, Middlesbrough, to produce cold-blast iron of a gray or foundry quality. It was in vain however that the burden of ironstone was reduced, that is the proportion of coke increased: the temperature of the hearth could not be sufficiently raised to produce any other quality than forge iron, the effect of the reduced burden being only to throw an increased temperature into higher regions of the furnace. The attempt was consequently abandoned; not however until it became obvious that the burden might have been still further diminished with only the effect of diffusing the hottest temperature into still higher regions of the furnace.

Whatever heat is imparted to the nitrogen of the atmosphere and also to the carbonic oxide generated in the furnace is of course delivered up again to the materials in the furnace, excepting only the portion lost by the temperature at which the gas escapes at the throat of the furnace. The effect of heating the nitrogen before its entrance into the furnace now becomes more clear. It has a shorter distance to travel up within the furnace before the maximum temperature is attained, for the simple reason that, having been partly heated already, it requires less time to become further heated to the temperature required in the furnace, having got the start by the amount of its initial temperature. Hence the fusing heat is generated nearer to the tuyeres; and this circumstance, together with the smaller expansion of hot blast compared with cold blast on entering the furnace, seems to furnish a satisfactory explanation of the more immediate effect of heated air in preventing diffusion within the furnace of the region of highest temperature.

As to the method of heating the nitrogen, it must be borne in mind that the heat generated in a blast furnace is obtained wholly or nearly so by the imperfect combustion of the carbon of the coke into carbonic oxide as the final result, a process by which theoretically only about one fourth the total quantity of heat is developed that would be obtained by the perfect combustion of the same carbon into carbonic acid, showing a loss in the fuel of about 75 per cent. of heat; since 1 lb. of carbon burnt into carbonic oxide developes only 2880 units of heat, whilst 1 lb. of carbon burnt into carbonic acid developes about 11700 units of heat. For although the combustion of the carbon of the coke in the blast furnace is partially or wholly into carbonic acid so long as the supply of oxygen is in excess, this condition applies only to the lower portion of the furnace nearest the tuyeres; and this carbonic acid becomes ultimately reduced to carbonic oxide by passing through the excess of carbon in the mass of incandescent coke occupying the upper portion of the furnace. If therefore the nitrogen be heated partially or wholly before entering the furnace, by any means involving the perfect combustion of the fuel employed into carbonic acid, it follows that a large saving in fuel must necessarily result; and to give an idea of the real influence of the nitrogen of the atmosphere on the consumption of fuel in the blast furnace, the writer has endeavoured to express numerically the effects produced by taking three different cases of the blast entering the furnace at the various temperatures of 50°, 650°, and 1150° Fahr. respectively. It is assumed that the air has to be heated within the furnace to 3000° Fahr. in each case; that 1 lb. of carbon burnt into carbonic oxide will develope 2880 units of heat, that is, will raise 2880 lbs. of water through 1° Fahr.; and that the specific heat of air is ·275, compared with that of water as 1·000. It is further assumed that 4500 cubic feet of blast enter the furnace per minute; and as 1000 cubic feet weigh 76 lbs., the weight of blast entering the furnace per minute will be 342 lbs., 77 per cent. of which or 263 lbs. weight is nitrogen.

In the three cases cited it will be seen that the work to be done within the furnace is to raise the temperature of the air through

2950° in the first case,
2350° in the second,
1850° in the third.

In the first case, namely to heat 263 lbs. of nitrogen through 2950°, there will be required

$$\frac{263 \times 2950 \times \cdot 275}{2880} = 74 \text{ lbs. of carbon per minute.}$$

In the second case, namely to heat 263 lbs. of nitrogen through 2350°, there will be required

$$\frac{263 \times 2350 \times \cdot 275}{2880} = 59 \text{ lbs. of carbon per minute.}$$

In the third case, namely to heat 263 lbs. of nitrogen through 1850°, there will be required

$$\frac{263 \times 1850 \times \cdot 275}{2880} = 46 \text{ lbs. of carbon per minute.}$$

These results show that to raise the temperature of the blast from 50° to 650° before it enters the furnace causes a saving in the blast furnace of 15 lbs. of coke out of 74, or about 20 per cent.; and that a further increase of temperature from 650° to 1150° occasions a saving of 13 lbs. out of 59, or about 22 per cent. To show that these calculations are not so merely theoretical as might at first be supposed, it may be here stated that in the writer's experience the raising of the temperature of the blast from 650° to 1150° at the Ormesby Iron Works has accomplished an actual saving of from 17 to 18 per cent. of coke in the blast furnace; and this was effected at an expense of coal outside the furnace of about one half the weight of coke saved within the furnace. The writer believes however that, were it in his power to compare two exactly similar systems of hot-air stoves, the additional fuel consumed outside the furnace would approximate more nearly to one third of the weight saved inside the furnace than to one half. But the difficulty of having to compare the ordinary cast iron stoves with the regenerative hot-blast stoves, by which the highest named temperature of 1150° is attained, is too great to allow of the comparison being made more precisely.

In the cold-blast furnace the method of heating the air is simply by its direct contact with the heated material and incandescent coke, and it is heated altogether at the expense of carbon burnt only into carbonic oxide instead of into carbonic acid. In the hot-blast furnace, by the more complete combustion of the heating fuel in the hot-blast stoves, exterior to the furnace, the nitrogen is heated not only at a cost of fuel represented by a saving of theoretically three fourths in the actual weight of coke required within the furnace to raise the nitrogen to the same temperature, but also with the further advantage that instead of burning coke it is coal that is used for the purpose. In other words, for every pound of coal economically burnt outside the furnace in raising the temperature of the blast, three pounds of coke will be saved within the furnace, whether the furnace be open or closed at the top.

It may be thought that a comparison made between an open-topped furnace where the gas burns freely as it escapes, and a close-topped furnace where no such combustion takes place, is not a fair one; and that the combustion of the gas at the throat of the open-topped furnace, by imparting heat to the materials at the throat of the furnace, would tell in favour of the consumption of fuel in the open-topped furnace. But facts speak otherwise, and it appears that there is practically no difference whatever due to this cause.

It will thus be seen that a definite limit to the height of a furnace is soon reached in practice; and that the advantage derived from increasing the actual height of a furnace may be partly secured by increasing the temperature of the blast, and thereby lowering the region of maximum temperature in the furnace.

The only question that remains is as to the diameter of the furnace. In reference to this dimension, the danger that has been alluded to from the formation of cold masses in the centre of a blast furnace serves as a caution against the more dangerous formation of cold masses attached to the sides of the furnace, technically called scaffoldings. It is obvious that, if the width of the boshes of a furnace be large in proportion to the height and the volume of the ascending gas, there will be a tendency to unequal diffusion of the heat imparted by that gas over the successive horizontal sections of the furnace, and irregularities in its working will consequently set in. There is then a limit to the diameter of the boshes, the largest of which yet in use is believed to be about 21 feet; beyond this size it appears very questionable whether any beneficial result would arise, though a furnace has been stated to be in course of construction at Cwm Celyn having a diameter of 24 feet at the boshes.

The nature of the materials of the charge in any contemplated increase of the dimensions of a blast furnace must be most scrupulously borne in mind. The density of the coke is the most important consideration; but next to that is the friability of the ironstone itself. In the Staffordshire district it would be useless to build furnaces of the height contemplated and actually employed in the Middlesbrough district, for the simple reason that the

Staffordshire coke is friable and would be crushed most injuriously by the weight of superimposed material.

It is thus evident that the actual dimensions of a blast furnace in any particular instance are much dependent upon special local circumstances; but the writer has endeavoured to point out the general principles which guide the determination of the dimensions to be adopted.

The President thought the paper that had been read was an excellent one and gave a clear explanation of the advantage of hot blast and the principles involved in the arrangement of the materials in a blast furnace. He enquired what had been found to be the effect of the internal distributing cone in the throat of the furnace at the Ormesby Iron Works, as regarded the quality of the iron produced, and whether there had been any difficulty in keeping the furnace up to the desired quality of foundry iron since the internal cone had been added.

Mr. Cochrane replied that the quality of the iron now made by the furnace was the same as the foundry iron made in the same furnace before the internal distributing cone was added; but the difference produced by the cone was this: that before its application, although the furnace would make as good a quality of foundry iron when in good working order, it was liable continually to be thrown suddenly to white iron, owing to irregularities in the arrangement of the materials in the furnace, causing them to reach the hearth in an imperfect state of fusion, so that white iron was produced notwithstanding the burden was the proper one for foundry iron; whereas since the addition of the internal cone no white iron had ever been produced with a foundry iron burden, but the furnace was now kept regularly to foundry iron without any irregularities occurring in its working.

The **President** enquired what was the construction and weight of the internal cone, and what was found to be its durability in that situation.

Mr. **Cochrane** replied that the cone was made of sheet iron and was suspended inside the throat of the furnace by four chains from the charging plate, as shown in the drawing; its weight was about 5 cwts. The cone had now been in regular use for about four months, and would probably have lasted ten or twelve months before requiring renewal, if that plan of charging had been continued in constant work; it was however only a temporary construction which he had adopted by way of trial, for the purpose of satisfying himself respecting the arrangement of the materials in the furnace top; and the entire furnace top was now in process of alteration to the ordinary plan of closed top with the cast iron lowering cone for charging, as shown in Fig. 3, Plate 58, since this served the same purpose of distributing the materials in the furnace as the internal distributing cone; a single large opening was also employed for taking off the gas at one side, instead of the annular gas chamber previously used.

Mr. J. E. **Swindell** enquired how the impossibility of making No. 1 foundry iron with cold blast in the Middlesbrough district was accounted for, and whether it was considered due to the more intractable nature of the materials in that district.

Mr. **Cochrane** believed it was entirely owing to the more intractable nature of the materials that it was impossible to make the best qualities of foundry iron with cold blast in the Middlesbrough district, because in Staffordshire No. 1 foundry iron could be produced with cold blast. The explanation he thought was as submitted in the paper just read: that with cold blast the air had to travel higher up into the furnace before a sufficient heat was obtained for the reduction of the iron ore; and it was possible also that the nature of the materials in the Middlesbrough district required a temperature which could not be produced at all with cold blast.

Mr. J. E. **Swindell** asked whether it was considered that the materials in the furnace really did melt nearer to the tuyeres with hot blast than with cold blast; he understood that practical men who had worked both hot and cold-blast furnaces stated distinctly that the materials melted nearer to the tuyeres in a cold-blast furnace than with hot blast.

Mr. Cochrane said the object to be aimed at in the blast furnace was to get the region of maximum temperature limited as much as possible in its extent above the tuyeres, and to leave all possible height of the furnace available for the absorption of the heat generated in the lower parts. No doubt with cold blast the materials were melting as close to the tuyeres as with hot blast, but the objection to the cold blast was that it caused them to be melting also considerably above the tuyeres, for a height of probably as much as 10 or 12 feet above. The object more correctly stated was therefore to bring down, not the point at which the materials *did* melt, but the point at which they *did not* melt; that is, to bring down the upper limit of the region of fusion, and confine the maximum temperature to the least possible height above the tuyeres: and he was fully satisfied that this was the effect produced by the hot blast as compared with the cold blast.

Mr. E. Reynolds suggested that the difficulties which had been met with in the working of the furnace arose from the construction of the closed top and charging valve, which appeared to be a reversing of the old mode still employed at the Butterley Iron Works, where the charging was done by means of a filling barrow, which carried the charge in a bucket at the end of a projecting arm reaching over the centre of the open top of the furnaces; each bucket consisted of a vertical cylinder, the bottom of which was closed by a cone held up against it, and the charge was dropped into the furnace by lowering the cone valve. By that plan, when the cone was lowered for charging, the tendency of the charge was to shoot outwards; but with the construction of the closed top shown in the drawings, when the charging valve was raised, the slope of the charging plate surrounding the valve would cause the material to be shot towards the centre of the furnace, and would thus occasion the difficulties that had been experienced. These he suggested might be obviated if the sides of the charging plate were more nearly vertical, so as to shoot the material less into the centre of the furnace, and agree more nearly with the vertical sides of the charging cylinders in the old plan used at Butterley.

Mr. COCHRANE did not see how such an arrangement of the charging plate could have been carried out with the construction of charging valve that had been employed at the Ormesby Iron Works, nor was the slope of the charging plate a point of importance after the internal distributing cone had been added. The object of having a charging valve that should be raised for charging, in place of the ordinary cone valve that was lowered in the furnace at each charge, had been to save as much height as possible in the furnace and admit of keeping the materials charged up to a higher level in the throat of the furnace. It had been a question therefore in the first instance between employing a much larger charging valve, so as to avoid all risk of the charges being shot into the centre of the furnace; or keeping the size of the valve as small as was compatible with maintaining the level of the materials in the furnace up to the full height intended: and it had been found, as the result of experience, that the original size of the charging valve, only 6 ft. 6 ins. diameter, was too small to prevent the charges falling into the centre of the furnace, although the difficulties arising from that cause had since been entirely obviated by the addition of the internal distributing cone for directing the materials outwards towards the sides of the furnace. At a neighbouring furnace however in the Middlesbrough district, where the same construction of closed top with lifting valve had been adopted, the valve had been made 9 ft. 6 ins. diameter instead of only 6 ft. 6 ins.; and the consequence of this increase in its size was that the charges were distributed sufficiently towards the sides of the furnace, instead of shooting into the centre, and the furnace was working admirably without any need of an internal distributing cone such as it had been necessary to have recourse to in the furnace described in the paper.

The PRESIDENT enquired what was the difference of size in the Staffordshire blast furnaces as compared with those in the Middlesbrough district.

Mr. J. E. Swindell said that the furnaces in the Staffordshire district were from 13 to 18 feet in diameter as a maximum, and not exceeding 45 to 50 feet in height.

The President asked whether the materials of the charges for the close-topped furnace described in the paper were broken to any particular size before charging.

Mr. Cochrane replied that the limestone was broken by hand labour to a size of about 4 to 6 inches cube; but the ironstone was taken as it came from the kilns, and no attempt was made to break it at all, as that had not been found to pay.

The President enquired whether the high temperature of 1150° Fahr., which had been mentioned as the heat of the hot blast at the Ormesby furnace, was the average temperature of the blast, and what was the extent of fluctuation in the temperature.

Mr. Cochrane replied that the blast was heated by means of Mr. Cowper's regenerative hot-blast stoves, and the average temperature of blast obtained was 1150° in regular working. The very outside fluctuation was about 200° during the four hours that each stove alternately heated the blast, the maximum temperature being nearly 1250° when the newly heated stove was first turned on, and the minimum temperature not less than 1050° at the end of the four hours' working of the same stove.

The President asked what had been the experience with reference to the durability of the regenerative hot-blast stoves, and whether any difficulty had occurred with any part of them.

Mr. Cochrane said he had now had these stoves in regular work for upwards of three years, and as regarded their durability they did not show the slightest signs of wear or deterioration, but appeared likely to last for an indefinite length of time. The only parts in which any difficulty had been experienced were the stop gas valves of the stoves; these gave some trouble at first in consequence of a condensation of tar upon them, which prevented them from fitting as tightly as was necessary to avoid leakage, and the tar afterwards ignited and cracked the valve seats; but that difficulty was now entirely got over by not allowing the gas to come into contact with the valve at the time the blast was passing through the stove, so that any leakage of blast, instead of escaping into the gas, was now discharged into the open air.

Mr. E. A. **Cowper** remarked that the regenerative hot-blast stoves heating the blast for the Ormesby furnace were the same that he had described at a meeting of the Institution four years previously, (see Proceedings Inst. M. E., 1860, page 54); and the advantages then anticipated from heating the blast in that manner to the high temperature of 1150° Fahr. had been fully realised in actual working. The temperature of 1150° was not attainable with common stoves, in which the heat of the blast seldom exceeded 650°, and could not be increased much beyond that amount on account of the heating being done by means of cast iron pipes. The regenerative stoves however afforded the means of raising the temperature to as much as 1250° or more, the blast being heated by direct contact with the hot mass of firebrick contained in the stove, which had previously been heated by direct contact with flame. The result of employing a blast of that high temperature had been as stated in the paper, that 17 to 18 per cent. of coke was saved in the blast furnace: and there was also an increase of about 20 per cent. in the quantity of iron made, while the quality of the iron was better than previously, more of No. 1 being made.

Mr. F. J. **Bramwell** observed that the arrangement of close-topped blast furnace described in the paper was one of the plans by which the whole of the gas was taken off from the furnace, and there was no combustion of gas out of the mouth of the furnace; and in connection with that arrangement it appeared to be considered that the sole object to be attained was that the materials in the upper part of the furnace should absorb as completely as possible the heat generated lower down. He believed however there was a general opinion that a certain beneficial chemical effect was produced by allowing some of the gas to burn out of the furnace mouth, so that its combustion there might operate in preparing the newly charged materials and rendering them more ready to be acted upon and deoxidised as they descended in the furnace. An open-topped arrangement, similar to that employed at Messrs. Schneider's furnaces at Ulverstone, had been described at the Liverpool meeting of the Institution last year (see Proceedings Inst. M. E., 1863, page 227), a large portion of the gas being taken off by a vertical tube inserted in the centre of the furnace throat, while the annular space surrounding the tube was left open for the rest of the gas to burn out freely at the mouth of the furnace; and that plan appeared to him to satisfy all the requirements, for while allowing so much of the gas to be taken off as was required for working the blast engine and heating the blast, it still left gas enough burning out of the furnace top to produce the heat necessary for the proper preparation of the materials, and also left the mouth of the furnace open so that the charging was done in the ordinary manner by hand. He thought therefore that an arrangement which allowed of combustion at the furnace mouth and of charging in the ordinary manner fulfilled the required conditions of a blast furnace better than one in which the combustion at the furnace top was entirely stopped by taking off the whole of the gas, and where the charging had to be done by special means in consequence of the top of the furnace being closed.

In reference to the irregular quality of the iron produced where there was any irregularity in the charging of the materials, he thought it most important that great attention should be paid to having the materials all broken to a uniform size for putting into the furnace. For where a chemical process had to be carried on, such as the reduction of the ironstone and other materials of the charge, it was impossible to expect uniformity of results without uniformity of mixture; and if large masses of ironstone and limestone were put into the furnace, they could not be so thoroughly and uniformly acted upon by the heat as if smaller pieces broken to a uniform size were used. A stone-breaking machine for breaking the limestone and iron ore for blast furnaces had been seen in operation by the members at the Liverpool meeting in last year, and had also been described at a subsequent meeting (see Proceedings Inst. M. E., 1864, page 20); which effected the breaking of the materials with great economy, and with a rapidity sufficient for all the purposes of a large ironworks; and he thought such a machine would be productive of great advantage by conducing to uniformity in the quality of iron made with a given burden.

He had not had an opportunity of seeing the regenerative hot-blast stoves at work for heating the blast, but they were an admirable adaptation of Mr. Siemens' regenerative system: he had seen the regenerative furnaces applied to other purposes where a very high temperature was required, and certainly nothing could exceed the success of their application in such cases. There was no doubt that the mass of firebrick in the regenerative stoves gave the means of heating the blast as high as 1150° Fahr. or upwards, and of maintaining it easily at that temperature, which it would be impossible to accomplish in the ordinary mode of heating the blast through cast iron pipes. Moreover in the regenerative stoves every particle of fuel was utilised, since the heat given out by it was taken up so completely by the firebrick in the regenerators that the chimney flue remained cool enough to allow of the hand being held in it; and the blast being afterwards heated by passing in the reverse direction through the same mass of firebrick, the heat was carried forwards by it into the blast furnace, and great economy was thus effected, the whole of the heat being thereby utilised, instead of a large amount of waste heat escaping to the chimney. There appeared no reason to doubt that the increase in the temperature of the blast from the ordinary heat of 650° to the high temperature of 1150° maintained at Ormesby was attended with the beneficial results that had been mentioned, as regarded economy of fuel in the blast furnace; and that being the case, it might be expected that a still higher temperature of blast would be found productive of yet greater economy. As to what temperature of blast would give the maximum of economical effect, if the question were one of merely melting the ore, no doubt the process of heating the air by means like the regenerative stoves, which utilised nearly the whole of the fuel, might be advantageously carried on until the air was made sufficiently hot to do the whole work of melting the ore without the use of any fuel at all in the furnace; unless indeed before that point were reached the highly heated blast should have an injurious effect on the walls of the furnace, which however he did not at all fear. But it must be borne in mind that the use of the fuel in the furnace was not merely to generate heat for melting the charge, but that one of its most important functions was to act chemically on the ore so as to fit it for reduction. It seemed to him probable therefore that the limit of useful effect in heating the blast would be reached at that point where its increased temperature would admit of the fuel in the furnace being reduced to the minimum quantity requisite to act chemically on the ore. What that quantity might be was a chemical question: but he had little doubt that the limit was sufficiently far off to allow of the temperature of the blast being still further increased with advantage; and he believed this increased temperature could be obtained by the use of the regenerative stoves, which he was very glad to hear had worked so successfully during the four years they had been in action.

Mr. **Cochrane** remarked that, as regarded the burning of the gas in the throat of the blast furnace, he was led to believe that the temperature of the ascending gas on reaching the top of the furnace was not sufficient to produce any chemical effect upon the materials, and the addition of a few feet height at the top of the furnace was only a question of absorbing the heat more completely from the gas before it escaped from the furnace. He had at one time considered that the combustion of the gas in the throat of an open-topped furnace had something to do with dispelling any foreign matter in the coke or the ironstone, or possibly finishing the calcining of any portion of the ironstone that had been imperfectly burned, or drying the materials and warming them more thoroughly previous to their descent in the furnace. But the results of subsequent experience had now led him to conclude that there was not any appreciable difference in yield between a furnace working with a totally closed top and one which allowed the combustion of the gas in the throat. The explanation of this fact appeared to be the same as that which applied to the burning of an ordinary candle, where the gas in the interior of the cone of flame remained so cold that gunpowder might be placed in it without being exploded; and in the same way in an open-topped blast furnace, the gas by the time it reached the top of the materials was at its lowest temperature, and it had still so much further to ascend before it came in contact with the oxygen of the air necessary to burn it, that the heat generated by its combustion at the furnace mouth, although large in amount, could not radiate back again through the ascending column of gas so as to impart any of its temperature to the materials lying in the throat of the furnace.

As regarded the breaking of the materials previous to charging, there could be no question that if they could be always broken to a uniform size it would be very advantageous to the working of the furnace. This was already accomplished to a considerable extent in the case of the limestone, which was broken by hand labour for the purpose; but in respect to the ironstone, he had no hesitation in saying that any attempt to break it into pieces of uniform size would be frustrated in the Middlesbrough district by the amount of waste made in crushing it, on account of the friable nature of the Cleveland ironstone.

Mr. J. E. **Swindell** mentioned that an attempt had been made eighteen years ago in a blast furnace at Wingerworth in Derbyshire to get the gas ignited and consumed close to the surface of the materials in the furnace throat, in order that the whole of the heat generated by the combustion might be utilised in the furnace. The furnace was about 25 or 30 feet high, with the top entirely closed, the charging of the materials being done through doors provided for the purpose; and a small opening furnished with a damper admitted air to the top of the furnace for the combustion of the gas. The result was that the gas was entirely consumed in the top of the furnace, and the heat produced was so great that the materials at the top were almost in a melting state. The furnace had been worked in that manner for a considerable length of time, but the results were altogether unsuccessful as to quality of iron made and economy of fuel, and the plan was therefore abandoned.

Mr. J. **Fernie** had been much struck with the very great waste of heat that must take place at the open-topped furnaces of Gartsherrie and other places in the neighbourhood of Glasgow, where the quantity of waste gas burning out of the furnace tops appeared largely in excess of what was observed in many English open-topped furnaces; and he could not help thinking the closed top or some other mode of taking off the gas and utilising it might be applied with great advantage to many of the Scotch blast furnaces.

The **President** enquired whether the iron produced was found to be stronger or better in quality in consequence of the high temperature of the hot blast described in the paper. He remembered that formerly iron used to be produced so strong that the pigs had to be cast with nicks in them for breaking, but latterly the strength had so much deteriorated that a pig would break by merely falling on the ground; and he feared that more attention was now paid to cheapness than to quality of iron.

Mr. **Cochrane** said he had not made any experiments to ascertain the actual increase of strength in the iron produced with the very hot blast employed at Ormesby, but he could state positively that there was an increase of strength, as shown by the fact that the work of breaking the pigs after each cast was now much heavier, which was a rough test of the increased strength. There was a decided improvement in the purity of the iron made with the hotter blast, which would no doubt explain its increased strength. In the Middlesbrough district it was found that a little scum of impurities rose to the surface of the melted iron in the blast furnace, which was sometimes very objectionable in casting; but with the hotter blast there was less of this scum rising, showing that there was increased purity of the iron produced. In fact as the greater part of the impurities in the iron arose from the coke, the smaller quantity of coke used with the hotter blast gave less opportunity for these impurities to pass into the iron.

Mr. J. **Anderson** thought it strange that makers of iron on a large scale should allow the question of quality to occupy so little of their attention. The fact that the tensile strength of different descriptions of iron in the pig ranged from as low as only 4 tons per square inch up to 15 tons, with all the strengths between, showed that there was something to be done by the iron maker, and that the founder had very little to depend upon previous to trial as to the kind of iron that should be used for any purpose, since with the inferior irons the strains to which they would be subjected in use must often approach very nearly to their breaking strength. He thought the iron maker should ascertain the exact quality of the iron which he made, so as to be able to state definitely how good it was in respect to toughness, elasticity, and ultimate tensile strength. If these points were more attended to, instead of merely the production of iron in great quantities, it would in the long run be the better for the country at large.

Mr. W. **Haden** remarked that if a superior quality of iron were desired it could always be obtained if a proportionate price were paid for it. But there were many other requirements also for which a very inferior quality of iron was quite suitable; and if these were to be overlooked, a large amount of the material in the various iron making districts would lie worthless. The great object to be aimed at in every district was to utilise the material of that district to the utmost extent.

Mr. J. **Anderson** thought that, if there were greater facilities for getting good iron, a proportionate diminution might be made in the dimensions of castings, compared with those made of the inferior iron at present employed; and if more care were bestowed upon getting the greatest strength from the ironstone of a district, and the chemical constituents of the iron were attended to, the minimum tensile strength of the iron in the pig might probably be brought up to 8 tons per square inch or upwards. Thus only half the weight of iron would have to be used in those structures for which the inferior iron was at present employed.

Mr. J. E. **Swindell** thought the only excuse for not using the better qualities of iron was their high prices; but the tensile strength of 8 tons per square inch that had been mentioned appeared to him to be considerably below the actual strength that was generally obtained from the best makes of pig iron. At his own works in the South Staffordshire district the tensile strength of bars 1 inch square of cold-blast iron cast direct from the blast furnace was found to be 14 tons in the regular make, though it was not possible for that strength to be guaranteed in all castings made from such pigs, because the metal might be so treated subsequently in the foundry as to have much of its strength destroyed. The mechanical qualities of any sort of iron, its strength, toughness, and elasticity, were the principal points to be regarded, he considered; and the question of chemical composition and the minute proportions of foreign ingredients mixed with the iron appeared to him of very secondary importance.

Mr. F. J. **Bramwell** concurred in thinking that the chemical composition of iron should be viewed as of secondary importance in comparison with its mechanical qualities. If a number of inferior descriptions of iron were found by chemical analysis to contain a certain foreign ingredient which was found to be absent from other irons of a better class, that afforded a presumption that the particular ingredient in question deteriorated the quality of any iron containing it: but the exceptions to this inference were found to be so numerous in practice that it would be a mistake to reject any iron merely on the ground of its containing some special ingredient, while its mechanical properties might notwithstanding be such as to place it among the class of good irons. He therefore considered the mechanical qualities were in every case those which should be first regarded. In describing the strength of any make of iron, one thing to be stated was the condition that the iron was in, whether in the pig or after a subsequent process of casting, as the strength was much affected by difference of the conditions in that respect. In the case of some iron from Nova Scotia which he had had occasion to test, he had found that in the pig it bore a tensile strain of only 7½ tons per square inch; but after repeated fusion and mixing with its own scrap, the same iron bore an average tensile strain of 18½ tons per square inch, while the highest strength obtained by that means was as much as 19⅝ tons per square inch, as proved by the testing machine at Woolwich, showing how greatly the original strength in the pig might be increased by subsequent treatment.

Mr. J. **Anderson** remarked that having lately given a good deal of attention to the properties of iron in its different characters of wrought iron, cast steel, and cast iron, he had come to the conclusion that the chemical composition of the metal was the great question. He had found that wrought iron which was most nearly pure, containing the least amount of carbon, had a tensile strength of about 20 tons per square inch, and in the irons of Scotland and the steely irons of Yorkshire the strength varied from that amount up to 28 tons per square inch, while cast steel containing 1½ per cent. of carbon had an ultimate tenacity as high as 75 tons; whereas in cast iron, containing the largest proportion of carbon, the strength declined to 8 tons and downwards as low as 4 tons per square inch. All these descriptions of iron, excepting the purest with the tensile strength of about 20 tons, had their strength increased by plunging them while in a heated state into cold water. He had also found that the facility of welding any description of iron was in proportion to its freedom from the chemical constituent, carbon, which increased its tenacity; so that the purer and weaker irons welded more readily than those containing more carbon and possessing greater tensile strength. Thus the steely irons of Yorkshire became very difficult to weld in the stronger qualities, and the next gradation in the scale was the mild steels which he was now using for guns. These had very nearly the same constituents as the Yorkshire iron, and were affected to nearly the same extent by being made red-hot and plunged into water. The various mechanical properties of the different descriptions of iron were now becoming generally understood, but the great question that still remained for solution was altogether a chemical one: namely, what it was that produced such great changes of quality in the different sorts of iron, and particularly what it was that caused iron to become so much stronger when heated red-hot and plunged into water.

Mr. P. D. **Bennett** thought the subject of the different qualities of various descriptions of iron was of the greatest importance to the makers of iron, and he would be very glad if an explanation could be given as to why there was so much difficulty in getting Staffordshire iron to stand tests which were borne by Scotch iron of much less cost. His own practice in testing iron was to have a test bar cast 2 inches deep by 1 inch wide with 3 feet between the bearings, which ought to carry a load of 28 cwts. in the centre before breaking, if the iron were of at all a good quality. But in the case of the Staffordshire district he had found it difficult to get any of the cheaper iron to stand that test, while Scotch iron would readily stand 32 cwts.; and to get Staffordshire iron to stand the same test as the Scotch, the price would be as much as 20*s.* to 30*s.* per ton higher than the Scotch. In some recent experiments with the best cold-blast Staffordshire iron he had succeeded after much difficulty in getting a test bar to stand a weight of 37 cwts., which was the highest test he had been able to attain with it; but the price in that case was as much as £5 10*s.* per ton as compared with only £3 10*s.* for Scotch iron of the same strength. He hoped therefore that the reason of this great difference would be more satisfactorily explained than had yet been done.

Mr. E. A. Cowper thought there was still much to be done in respect to the chemical investigation of the different qualities of iron, in order to ascertain clearly what was the cause of the differences that were met with; for when this was known, so that the quality of any desired sort of iron could be fully described, he had no doubt the iron makers would find the means of producing that quality of iron readily enough. At present chemistry had not gone far enough in this subject; for in a recent case one of the strongest irons known had been rejected on chemical reasons alone.

In reference to increasing the strength of iron by heating it red-hot and plunging it into cold water, it was found very advantageous, in the case of casting chilled rolls, to melt and cast the iron into cold water two or three times beforehand. He did not know what change this made in the nature of the metal, but it had the effect of causing the iron to chill more completely in the final casting, and thus increased the hardness and durability of rolls cast in that way.

Mr. J. Anderson observed that a great deal had already been accomplished and was still in process of being done by government towards ascertaining the chemical qualities of iron, and to a certain extent these endeavours had been successful; but because chemical investigation had not always led to correct results at present, it ought not on that account to be disparaged.

Mr. F. J. BRAMWELL thought the value of chemistry in connection with the properties of iron should not be depreciated; but on the other hand, when the sole object was to get iron that should satisfy certain mechanical requirements, if the chemical test and the mechanical test were at variance, it was a mistake to accept the chemical test in lieu of the mechanical. In any case of a discrepancy between the two, the test which was practical should be adopted, and not that which was only a means of arriving at the practical by another road.

The PRESIDENT considered the experiments and researches that had been referred to as being made by the government must tend to a good result ultimately, and were leading the way for further investigations by individual makers and consumers of iron, who were all anxious to get better iron. A very elaborate machine was now in course of construction by Mr. Kirkaldy, for the purpose of testing iron in respect to all its various mechanical properties, which would enable the makers of iron to ascertain with great accuracy the quality of the metal which they produced.

He proposed a vote of thanks to Mr. Cochrane for his paper, which was passed.

The Meeting was then adjourned to the following day. In the afternoon the Members were conveyed by special train, granted for the occasion by the Edinburgh and Glasgow Railway Company, to visit the Mugdock Reservoir of the Loch Katrine Water Works, with the Straining Well, the Outlet of the Loch Katrine Aqueduct, and the Delivery Sluices for the supply of Glasgow. The Members were received at the Milngavie Station and accompanied over the works at Mugdock by the Lord Provost of Glasgow and the authorities of the Water Works; and returned to Glasgow in the evening by special train.

The Adjourned Meeting of the Members was held in the Institution Rooms, St. George's Place, Glasgow, on Wednesday, 3rd August, 1864; ROBERT NAPIER, Esq., President, in the Chair.

The following paper was read:—

ON IMPROVEMENTS IN HEAVY TOOLS FOR GENERAL ENGINEERING AND IRON SHIPBUILDING WORK.

By Mr. JAMES FLETCHER, of Manchester.

During the last thirty years the great rise and progress have taken place in the construction and application of general Engineering and Iron Shipbuilding Tools, their manufacture now forming a very important branch of mechanical engineering. Forty-five years ago, at the commencement of the writer's career as a mechanic, tools were of a very rude and primitive description, the lathe and drill being about the only ones then in general use; slide lathes were possessed only by a few persons, being made with great labour and expense, and very inferior in point of workmanship.

The introduction of the planing machine however and its subsequent development effected an entire change in the manufacture of tools and machinery of every class, giving the means of carrying out with facility many works which had been left unattempted previously as too expensive or impracticable, and opening the way for improvements and invention generally; and in a short time these machines became indispensable in every workshop. The slide lathe became then comparatively easy of manufacture, and in conjunction with the planing machine and self-acting drill formed a most important feature in the advancement of engineering work. Still much remained to be effected: a large proportion of work was done by hand, especially the smaller portions of machinery, until slotting and shaping machines were brought into use, and special tools adapted for all parts where a quantity of work was required to be produced. By the gradual introduction and perfecting of the regulator screw, the wheel cutting engine, standard gauges, large surface plates, long straight edges, and scraped surfaces, combined with the improved tools, not only was the amount of manual labour considerably diminished, but the work was done more expeditiously, and a much greater degree of accuracy was attained, whereby the workmanship in all classes of machinery was remarkably improved and at a great reduction in cost. As engineering skill was brought to bear on schemes which could not previously have been carried out, so were tools enlarged and new ones invented, to meet the exigencies of new works; until engineers and others became really dependent for the accuracy and execution of their work upon the tools that could be employed for the purpose. The steam engine, with all the inventive genius that has been concentrated upon it, would without these tools have still been most imperfect in construction, and would have formed a wide contrast to the engines erected at the present day, in point of excellence of workmanship, durability, and cost. Many instances could be given where tools of unusually large dimensions or the most minute description are indispensable for the execution of the work required.

The great change which has taken place in the substitution of wrought iron for wood or cast iron, especially in ship and bridge building, is a subject worthy of special attention. In ship building the use of wrought iron has advanced with such rapid strides during the last twenty years as to cause a complete revolution in the trade. The transition was so sudden and the demand so great that much difficulty was experienced in procuring a sufficient number of the necessary class of workmen, until those who had previously been employed as shipwrights in building wooden vessels were in a short time enabled, by the assistance of improved tools and appliances, to compete with more practised hands, and to cope easily with the heavy modern work. Improvements in the construction of iron ships were then rapidly developed. New tools were called for and produced, by means of which the work has been materially improved and facilitated; the edges of the plates are now planed to make perfectly fitting joints, and multiple drilling machines are rapidly coming into use for drilling a large number of holes at once in the plates or keel bars.

Another important feature in connection with improved tools is the direct application of steam power to individual machines, especially those for the purpose of punching and shearing plates or cutting bars, &c., by the combination of a small steam engine with each machine; thus rendering the machines portable, entirely self-contained, and independent of other sources of driving power, and thereby saving in many instances the necessity of running a large engine and quantity of shafting to drive only one or two machines, when pressed for the work upon which they are engaged, and entirely dispensing with shafting and the usual attendant expenses. By this means and by the use of an underground steam pipe with branches at convenient points, either in workshops or along the sides of docks, these machines may be moved about to any part required, and thus obviate the inconvenience and loss of time in carrying work to and from the machines. Steam pipes of great length are now being used and are found very satisfactory for purposes of this description; and this plan makes a much more convenient and less costly arrangement than shafting, which requires constant attention.

In the earlier construction of the Lathe the slide rest was the first great step towards the principle of the slide lathe, and no doubt led to that invention, which was considered impracticable before planing machines were made of sufficient magnitude to plane a lathe bed of even small dimensions. A few slide lathes had indeed been made, the beds of which were composed of a timber framing, covered with iron plates on the upper side to preserve the surface, similar to those which were previously used for the ordinary hand lathes, with the exception that the outer edges of the iron plates were made of suitable shape to form the Vs for the carriage to slide upon. It was not however until some time after the introduction of the planing machine that, the cost of workmanship being considerably lessened, slide lathes came into general use and their utility was fully acknowledged and attention directed to their improvement.

The application of a screw to the slide lathe, so as to render it capable of both sliding and screw-cutting, was the next important improvement; and a great amount of time, perseverance, and capital was expended by a few persons in endeavouring to perfect this portion of the lathe. A short screw was first made as accurately as possible, with the rude means then possessed, from which one was cut double the length, by changing the turned bar end for end in the lathe after cutting one half. Subsequently by following out this principle screws were capable of being made of any length required.

After this the surfacing motion was introduced; and also the use of a shaft at the back of the lathe, in addition to the regulator screw, for driving the sliding motion by rack and pinion, instead of both the motions of sliding and screw-cutting being worked by the screw alone. For it was found that the threads of that portion of the screw nearest the fast headstock, being most in use, were worn thinner than the other parts; and in consequence the lathe did not cut a long screw with the degree of accuracy which it otherwise would have done.

Thus step by step improvements were gradually brought forward; the four-jaw and universal chucks and other important appliances were added, so as to render the lathe applicable to a great variety of work, even cutting spiral grooves in shafts, scrolls in a face plate, skew wheels, and also turning articles of oval, spherical, or other forms. The duplex lathe, with one tool acting in front and the other behind the work, is also found to be a very useful arrangement for sliding long shafts, cast iron rollers, cylinders, and a great variety of work, where a quantity of the same kind and dimensions has to be turned.

The lathe shown in Fig. 1, Plate 59, is an improved lathe designed for the purpose of turning long shafts, screws, or other articles. The bed A is 40 feet long, cast in one piece and planed the entire length at once. It is provided with two pairs of headstocks, placed right and left hand, each pair having its own carriage and tool rest, and working entirely independent of the other; the one pair B B being 15 inches high to the centre, and the other C C 12 inches high. In connection with the larger headstocks B B is a regulator screw running through the entire length of the bed, by means of which, when the other headstocks C C are removed, a screw 35½ feet long may be cut at once. The smaller headstocks C C, by means of a separate shaft at the back of the lathe, are capable of sliding an article 25 feet long, and can also if required be provided with a screw-cutting arrangement. Thus this lathe possesses the advantages of being used as two lathes for work of an ordinary character, but at the same time a very long shaft may be turned when required. In many workshops a long lathe is an absolute necessity, although the whole length of the bed may not be required many times during the year; and unless some similar arrangement to the one above described is adopted, a large portion of the lathe bed, taking up valuable space, would remain idle and useless the greater portion of the time. Again in sliding long shafts the two carriages and tools may be in operation at once upon the same piece of work, and thus economise time. The headstocks being placed right and left hand, the loose headstocks are thus able to accommodate each other to the different lengths of work, thereby avoiding the necessity of moving the fast headstock and top cone pulley when any work above half the total length of bed is to be turned.

Figs. 2, 3, and 4, Plates 59 and 60, represent a slide lathe for turning large marine-engine crank-shafts or other articles up to 40 tons weight, or screw propellers up to 20 feet diameter. The headstocks B C are 4 feet 6 inches high from the face of the bed, which is 40 feet long. The main driving spindle D is of cast iron, 18 inches diameter in the front bearing and 12 inches in the back bearing, arranged as an ordinary treble-geared lathe which can be worked single, double, or treble power. The cone pulley E, the largest speed of which is 3 feet 6 inches diameter by 6 inches wide, runs loose upon the spindle D. The faceplate F is 12 feet diameter and has on the back a large internal toothed wheel G, Fig. 3. By means of two pairs of driving pulleys on the countershaft, the lathe may be worked at thirty different speeds, to suit the diameter of articles to be turned. The fast headstock casting B is in one piece, and without spindle or appurtenances weighs 11¼ tons. It is tied to the bed A by the tie plates H, Fig. 2. The bed is 10 feet wide over all, and is composed of two lathe beds AA, Fig. 4, each cast in one piece 40 feet long, and held firmly in a parallel position by distance feet or foundation plates K, having strips and bolts to bind the beds in their places. When it is required to move the bed endways to accommodate any large article on the faceplate, the strips in the distance feet K are slackened so as to allow the two long beds AA to slide through them, the motion being given at the end by means of worm wheels and screws L, Fig. 2. The end foot or distance piece K nearest the fast headstock B is fixed to the long beds AA and travels with them upon the tie plates H, so as to support their ends whilst turning articles on the faceplate F. Two self-acting sliding carriages M and N are employed, Fig. 2, upon one of which M, Fig. 4, is a slide rest of ordinary construction and great strength; the other carriage N has a rest made very narrow, with a wrought iron tool slide, and is for the purpose of turning out crank sweeps. The self-acting motion is driven by a strap from the spindle D to a pulley O at the back of the lathe, Fig. 3, and is provided with a reversing apparatus to enable the carriages to slide in both directions. This motion can be thrown out of gear independently in either of the carriages M and N, which are provided with an arrangement for moving them on the bed by hand. An eye bolt is screwed in the front part of the loose headstock C, and a corresponding one upon the nearest carriage N, so that the two can be coupled by a short chain or shackle, and the loose headstock C can thus be drawn upon the surface of the bed A to any required position by the hand motion of the carriage N. The total weight of this lathe, which is now in course of construction for the Lancefield Forge in Glasgow, will be upwards of 70 tons.

The Planing Machine is one of the most important tools in use, and has done more towards the advancement and success of engineering work than any other invention, with the exception of the lathe; and has passed through a great number of changes since its first introduction down to the present time.

In the first planing machines the table was moved by means of a chain winding on a drum, as in the old hand machines.

But this mode was found to be very objectionable: the cut was unsteady, and when the tool was suddenly relieved at the end of its cut, the table had a tendency to spring forwards; it was also driven at the same speed both forwards and backwards, and thus a great loss of time was occasioned. This was much improved upon by the use of a rack and pinion, arranged to give a quick return motion, and also afterwards by the screw arrangement. Much difference of opinion has existed as to the relative value of the rack and the screw for driving the table of planing machines. The writer will not therefore go into this question further than to state that his own long experience in this class of machines, after having made a large number with both appliances, has led him to the opinion that the rack is decidedly the most preferable mode of driving.

In some of the earliest planing machines the **V**s were made inverted, evidently with the idea of preventing any cuttings that fell upon the wearing surfaces from remaining upon them. They proved however to possess no advantage even in this particular, as the finer portions of the cuttings still adhered; and in addition it was found that from the motion of the table the oil by its own gravity would not remain upon the surfaces, and thus caused them to cut and wear away quickly. They were afterwards made an ordinary **V** shape and found to answer much better, as the **V** formed a reservoir to contain the oil in a groove at the bottom, from which it was raised at each stroke by the motion of the table and the apparatus attached for that purpose. The **V**s have been constructed of different angles and widths of surface; but it is the writer's opinion that at the present time many machines are made with the angle too obtuse, and the surfaces widened to too great an extent. In machines with very shallow **V**s, taking a heavy cut off a light article with the tools on the uprights, the table is liable to shift sideways, causing the tools to dig into the work and occasion much mischief. Also with very wide **V**s the table when making short strokes cannot work the oil up to the top of their surfaces, and thus allows them to cut or gall. The writer has in use a planing machine with a bed 54 feet long, the **V**s of which, shown one quarter full size in Fig. 5, Plate 61, have only 2 inches of surface on each side, and are planed to an angle of 85 degrees. This machine has been working upwards of twenty years, and for the last six years both night and day; it has been employed during the whole of that time upon very heavy work, ranging from 5 to 20 tons. The Vs are still in good condition, apparently very little worn, and the work the machine does is at the present time perfectly true. The bed is in three parts jointed and bolted together, and the table in two parts; since at the time it was made there was no machine capable of planing a very long piece, and this was considered to be one of the largest then in existence. The writer has also a planing machine made about the same period with a V on one side of the bed and a flat surface on the other, which plan he found was very objectionable, on account of the two surfaces not wearing equally and the oil working off the flat surface.

The planing machines were further improved by the use of two toolboxes on the cross slide, and by the application of slide rests or toolboxes fixed upon the uprights, self-acting vertically, for planing articles at right angles to the tools on the cross slide. The reversing toolbox is a very ingenious and useful contrivance for planing flat surfaces; but that plan is not so well adapted for general purposes. Planing machines have like other tools been specially adapted to a great variety of work, and the writer has made them with different numbers of tools up to as many as sixteen, all of which were in operation at once.

The great changes which have lately taken place in the manufacture of wrought iron and steel ordnance, and the revolution they have caused in the construction of vessels of war, have called into requisition a great many alterations and adaptations of the present machines, as well as many entirely new ones. The planing machine especially has been called upon to do work of a very curious and intricate character, namely that of planing the edges of armour plates to different curves, shapes, or angles. In most cases this has been accomplished by a pattern bar of iron or steel, placed on edge in a small chuck fixed upon the surface of the table, adjustable by set screws, and shaped to the form to which it is required to plane the edge of the plate; as the table travels, this bar, which runs between two circular rollers attached to the underside of the tool slide, moves the tool sideways according to the amount of curve in the shaper or guide bar, the toolbox being disconnected for this purpose from the screw in the cross slide.

Figs. 6 to 9, Plates 61 and 62, represent one of the Duplex Planing Machines made by the writer. This machine is arranged with double beds A A and double tables B B, Fig. 8, each table having a separate set of gearing, with starting, stopping, and feed motions. There are two toolboxes C C on the cross slide D, each of which is independently self-acting, so as to work with its own table. Thus the two tables may be used separately as two smaller machines working independently of each other and capable of planing different lengths of work at the same time; or when planing a large article the two tables, gearing, and motions may be coupled, so as to form one large machine: an arrangement rendering the machine capable of doing a great variety of work. Also one table may be fixed stationary as a bed-plate, to bolt awkwardly shaped or long pieces of work upon, whilst they are planed by a slide rest fixed upon the other table. When used as one machine, both sets of straps and gearing are in operation, and are reversed by the stops of one table only, so as to ensure the straps moving at the same time.

The machine shown in Figs. 6 and 8, Plates 61 and 62, is capable of planing articles 10 feet wide and 10 feet high. The racks on the underside of the tables B B are 3 inches pitch, with stepped teeth, as shown enlarged in the plan, Fig. 7; the wheel E working into the rack is 3 feet 9 inches diameter at the pitch line, and is driven by a smaller pinion F, Fig. 6; the large wheel E being only for the purpose of transmitting the power from the pinion F to the rack. By this arrangement the large wheel E has a better hold upon the rack, and a steadier motion is obtained; and also the pulleys and driving gear G can be placed entirely behind the face of the uprights H, so as to leave the front of the machine perfectly clear, that the straps may not be in the way when taking the work off and on. The pulleys G being below the ground line may be driven by a horizontal underground shaft at the back of the machine, and no straps will then be visible. The writer has made machines of this description with beds 40 feet long to plane work up to 14 feet in width, the beds of which were constructed the same as shown in Fig. 9, being made in two halves A A, which are jointed longitudinally with a projection I on one half fitting into a corresponding recess in the other, and securely fastened by bolts at intervals throughout the entire length.

This machine is particularly well adapted for planing armour plates. Two plates can be planed at once on each table, one being placed upright and the other horizontal, so as to be operated upon by the tools on the cross slide and the upright at the same time; or whilst two plates are being planed on one table, the workman may be fixing two more on the other, and thus keep the machine constantly employed. One workman is sufficient to attend to both sides of the machine, thereby saving labour. By having a stationary table fixed at one side of the bed, upon which the four ends of four other armour plates are bolted, and adding an angle bracket and slide rest upon one of the moving tables, the four ends are planed at the same time.

The Slotting Machine, of which the engineers in Glasgow can justly boast the heaviest examples, was originally introduced for cutting small wheels, levers, &c., mostly for self-acting mule and loom work; and was afterwards adapted to a great variety of work by the application of a circular table, which was an improvement of the greatest importance, especially in large machines for slotting or shaping large cranks or other similar work; this is now done to such perfection as to require merely drawfiling and polishing to give the work a perfect finish. Many kinds of quick return motions have been employed for the purpose of saving time in the return stroke of the tool, and to give it a regular and steady movement in the cutting direction. Of these the principal are the eccentric wheels, the eccentric motion, and lastly the lever motion, which makes an excellent and steady movement and is now very much applied to shaping machines.

One of the large slotting machines made by the writer has a stroke of 3 feet, and the framing is capable of taking in an article 12 feet diameter; it has compound slides and a self-acting circular table 6 feet diameter. The ram moves in a vertical slide, which can be raised or lowered to suit the depth of work on the table, so as to form a support to the ram when taking a heavy cut. The motion applied to the tool slide is the lever and connecting rod, arranged so as to gain power and give an almost uniform motion in the cutting direction and an accelerated speed in the return stroke.

A difference of opinion exists as to the best form for constructing slotting machines, whether with the double standard, or the projecting single frame. For machines required to take in a very large diameter, the writer would give the former plan the preference.

Figs. 10 to 14, Plates 63 and 64, show a Double Lever Punching, Shearing, and Angle Iron Cutting Machine. The strong hollow cast iron frame AA is planed at each end for the reception of the punching slide B and the shearing slide C. The machine is put in motion by a steam engine D, Fig. 11, fixed upon the outside of the framing, and connected to a crank pin in the flywheel E, driving by the pinion F on the first motion shaft into the large wheel G, Fig. 12, which has cams H cast on each side in opposite positions, so as to actuate the levers KK alternately. These cams are provided with circular rollers, which run against the underside of the levers K during the operation of punching or shearing, and thus prevent any scraping or friction of the surfaces in contact. The levers K are of wrought iron, steeled where operated upon by the cams and where they work in the slides B and C, having the pins I for their fulcrums. The punching slide B, shown enlarged in Fig. 14, is provided with a block J, which can be drawn out from under the end of the lever to throw the punch slide out of gear. At the shearing end C, shown enlarged in Fig. 13, an adjustable stop L is added immediately in front of the shears, for holding down the plate whilst shearing, and thus causing it to be cut square on the edge: this takes the strain of holding down the plate from the workman, and prevents short pieces of metal from getting down between the cutters and breaking the machine.

Upon the end of the centre shaft is forged an eccentric M, Fig. 10, working into a block in the ram N, the lower end of which is provided with suitably shaped cutters for shearing bars of angle iron O. This slide is placed at an angle of 45 degrees, and has also a disengaging motion, so as to be thrown out of gear whilst a long bar of angle iron is being put between the cutters and set to the proper place or marks for being cut off correctly. This slide may also if required be placed in a vertical position for cutting straight bars. In cutting long bars of bent angle iron however, with the slide N placed in a vertical position, one portion of the bar would project either upwards or downwards at an angle from the ground, and would consequently be very awkward for the workman to hold; but by placing the slide at an angle, as shown in Fig. 10, the bars are kept in a horizontal line parallel with the ground whilst being cut.

This machine possesses all the advantages of the old lever machine and the eccentric machine combined; the former of which has long been acknowledged to be the most simple and useful. The cams H, Fig. 12, are constructed of such a shape that the operation of punching or shearing is completed and the slide returned to the top in half a revolution of the machine, the whole slide remaining stationary during the other half revolution whilst the workman is adjusting the plate for the next stroke. This enables the machine to be worked one third quicker than eccentric machines, and still leaves the workman as much time to move the plate; since in eccentric machines the punch or shears is always being either raised or lowered, instead of being stationary during part of each revolution. The levers KK are left sufficiently long and heavy at the tail end to overcome the weight of the slides B and C and the friction of the punch or shears upon the work. Many of the old machines were made without rollers either in the lever end or in the cam; and in consequence of the wear which took place, the stroke of the punch or shears was gradually lessened until the worn out parts had to be renewed. By the application of rollers however in the cams H, these objections are entirely obviated; and instead of scraping the oil from the wearing surfaces, the roller tends to keep it on.

For the purpose of obtaining greater accuracy in dividing out the holes in bridge plates, boiler, or ship plates, a dividing table has been used, and machines have been arranged to punch several holes at once. This was certainly a great improvement upon the old method, since in addition to the accuracy attained very much more work was accomplished in the same amount of time. Still the work was not of a satisfactory description: in punching the holes the iron is disturbed or fractured for some little distance round the hole, thus weakening the plate; and in consequence of the taper which there must necessarily be in all punched holes, the rivets do not thoroughly fill up the space, especially when more than two plates are joined together.

The faults of punched work above mentioned were so apparent when wrought iron bridge building became general, that they led to the introduction by Messrs. Cochrane of the Multiple Drilling Machine, described at a former meeting of the Institution (see Proceedings Inst. M. E., 1860, page 201), for drilling a large number of holes at once in bridge plates.

It has been found desirable to make this principle of drilling machine more universal in its application, and a machine for this purpose is shown in Figs. 15 and 16, Plates 65 and 66. The strong base plate AA extends the entire length of the machine, about 18 feet, with three circular openings along the centre line, large enough to admit the hydraulic cylinders C C, by which the table BB carrying the plate to be drilled is raised and pressed against the drills with the necessary force. The end frames DD are bolted to the base plate, and upon them are fixed guides adjusted to each corner of the table; they also support the girder EE, which carries the drill frames. The ends of the girder are fitted in planed grooves, and it is made in halves, which can be set wider apart without altering the gearing, by inserting cast iron packings of the requisite thickness and longer bolts at the joint F,

Fig. 16. The two halves of the girder can also be turned with the drill frames inwards if required, and adjusted to a distance of 4 inches apart for the two rows of holes and upwards.

Each drill is held in a separate frame G, as shown enlarged in Figs. 17 to 20, Plate 67. These frames are all bolted on the girder E at the proper distance apart by means of bolts, the heads of which are in T grooves cast and planed in the girder, Figs. 18 and 19. Two small projections on the drill frame G are planed to fit the recesses of these grooves, as seen in Fig. 18, and the drill frames G are thereby all held at exactly the same height and are easily moved longitudinally to any position along the girder E. Each drill spindle is fitted with an adjustable tail pin and lock nut H, which receives the upward pressure of the spindle; and a conical bearing is provided at the lower end of each frame G, which prevents the drill spindles from wearing out of truth. The drills are all turned parallel for a short distance at the upper end, as shown enlarged in Figs. 21 and 22, and fit in parallel sockets, which admit of short drills being adjusted to the same length as longer ones, by putting some small burrs or punchings from the punching machine of the required thickness into the drill sockets above the drills; and the drills are fastened in the sockets by a set screw.

Each drill spindle is driven at the top by a pair of spur mitre wheels II, which may be described as each consisting of a short section of a 3¾ inch diameter twelve-threaded screw, of which the threads are about 12 inches pitch; that is to say each thread or tooth if continued would make one complete turn round its shaft in 12 inches length. A long steel shaft J, 2¼ inches diameter, with a groove throughout its length, passes through each drill frame G and its vertical spur mitre wheel I, giving motion to each drill spindle. This shaft is driven by a pair of strong bevil wheels K, Fig. 16, in the proportion of 1½ to 1, the larger one being on the shaft J; and the wheels K take their motion direct from the pulley shaft L, which is driven with pulleys 3 feet diameter and 6 inches wide, and runs at about 90 revolutions per minute, giving about 60 revolutions per minute for the drills.

The application of the spur mitre wheels II, Figs. 17 to 20, in this machine, for driving the drill spindles, enables the spindles to be arranged in such a manner that they are capable of being moved to suit different pitches of holes. In consequence however of the wheels II being 3¾ inches diameter, holes could not be drilled at a less pitch than that dimension with a single driving shaft J; but another application of the same mode of driving is shown in Figs. 17 to 20, by means of which the drill spindles can be got to within 2½ inches from centre to centre, with the same diameter of driving wheels I: this is effected by using two long steel driving shafts J J, instead of a single one as previously described, each shaft driving every alternate drill spindle.

The hydraulic cylinders C C, Figs. 15 and 16, are similar to those of hydraulic presses, and are used to raise the table with the work on it up to the drills, instead of gearing which would necessarily be much slower. A pair of strong 1¼ inch diameter pumps, worked by eccentrics on a shaft, force water into an accumulator, which consists of an upright cylinder fitted with a piston properly weighted; and there is a self-acting apparatus which throws the pumps out of gear when the accumulator is full. The hydraulic cylinders are connected with the accumulator by a two-way cock; and on turning the water on, the table B immediately rises. When the pressure is to be removed, turning the cock back stops the pressure from the accumulator, and at the same time allows the water to escape from the cylinders, causing the table to fall immediately. The working pressure of water is about 3 cwts. per square inch, which produces a pressure of about 6 cwts. per drill. A plate is drilled in 12 to 15 minutes. A strong parallel motion gear M is fixed under the drill table B to prevent it from lifting at one end when only the drills at the other end are being used, or when only one row is in use.

These drilling machines are now being used by Messrs. Kennard for drilling the plates and bars required in the main girders of the new bridge to be placed over the Thames at Blackfriars. The truth of the drilled holes is so complete that when a number of plates with holes drilled for 1 inch pins are put together indiscriminately, and four turned pins passed through the corner holes, the holes fit so accurately throughout the entire lot of plates that a pin 1 inch diameter can be driven through the lot at any hole with a light hand hammer. In consequence of this superiority of the work, a great diminution in the cost of labour takes place in putting the parts together, saving the drifting of the holes and the strain put upon the plate which necessarily takes place when rivetting punched holes. In addition to this the fibre of the iron retains all its strength and tenacity, and there can be no doubt that the extra work of manufacture is fully compensated for by the greater strength of construction, and the decrease of cost in putting the plates together.

Several other useful machines are constructed for bridge and ship building purposes, amongst which may be named:—a machine for shearing plates up to 1 inch thick with revolving circular shears; machines for planing plates with a travelling tool, and also with a revolving circular disc containing a number of tools; and machines for bending garboard strakes, angle iron, and deck beams for ships.

A Nut Making Machine is shown in vertical section in Figs. 23 to 25, Plates 68 and 69; the principal features of which are the manufacture of nuts from a heated bar of iron at a single operation, by cutting off from the bar a piece to form the blank, which is swaged into shape and the hole punched through it while still hot. The blank is powerfully compressed between the pair of swages, while in the diebox, before the hole is punched, in order to make the nut solid and to shape it with smoothness and precision; and the hole is then punched while the nut is still confined in the diebox and under the heavy pressure of the swages, so that it is prevented from bursting or straining during the operation of punching. Figs. 24 and 25, Plate 69, illustrate the working of the machine, in which the end of the heated bar A being pushed up to the stop B is cut off by the descent of the diebox C on to the stationary die J; and the blank cut off being enclosed in the diebox C is then subjected to severe compression by the descent of the upper swage I, which works within the diebox C and fills it closely. The blank is then punched by the descent of the punch D, whilst still under compression in the diebox C; and the finished nut is liberated by the rising of the diebox C and punch D, whilst the upper swage I remains stationary and pushes the nut out below.

The diebox C, Figs. 24 and 25, is carried on the crosshead E, and consists of a cast iron block, into which is fitted the steel die having a hole to correspond with the shape of nut required to be made. The die is held down in the diebox by a circular wrought iron plate or washer let into the recess in the top of the block. The upper swage I is made of steel, and corresponds in size and shape with the diebox in which it is to work; the upper end is enlarged, to prevent it from dropping out when the diebox rises. The hole drilled through the centre of the upper swage I, for the punch D to work through, is made larger at the upper end, and small enough at the lower end for about half an inch of its length to fit the bottom end of the punch D, which makes the hole in the nut. The bottom face of this swage I is slightly recessed, in order to form the impression of a washer upon the upper face of the nut. The lower swage or stationary die J is made of steel, and has also a hole through its centre for the reception of the burr punched out by the punch D.

The end of the heated bar A, Fig. 24, is laid upon the rest F, which is fixed upon the crosshead E that carries the diebox; and as soon as the knocker G, Fig. 23, has passed from between the upper and lower swages, the bar is pushed forwards up against the stop B, as shown in Fig. 24. The cam H, Fig. 23, upon the main driving shaft O of the machine, then depresses the crosshead E by means of the lever K; and the blank to form the nut is thus sheared off from the end of the bar A by the diebox C, and enclosed within the diebox, as seen in Fig. 25. For although the diebox C, at the moment of beginning to descend, is filled by the swage I, there is nothing to cause the descent of this swage until after the blank has been sheared off and enclosed in the diebox; then the crosshead E comes in contact with the check piece L, which presses upon the top of the swage I, and the further descent of the crosshead through the last portion of its stroke thereby compresses the blank between the swages I and J, while still confined in the diebox. The second cam M, Fig. 23, upon the cam shaft O, now draws down the other crosshead N, in which is fixed the punch D, Fig. 25, for perforating the blank. The cams H and M are so shaped that the punch is made to pass down through the blank and out again, before the blank is relieved from the pressure of the swages; so that the metal is strongly compressed both before the punching and during the whole time the punching is being performed. After the punch has been withdrawn, the diebox C is carried up again by the return motion of the cam H; and the finished nut being tight in the diebox would be carried up with it, but the swage I is prevented from rising through more than half the stroke of the diebox, by means of the set screw P, Fig. 24, which stops the ascent of the check piece L. The nut is thus pushed out of the diebox by the swage I, and is ready to be knocked off by the revolving arm G, Fig. 23, which is driven by bevil wheels from the cam shaft O.

The dies, swages, and punch are so fixed to the machine that they can easily be removed and replaced by others of different sizes: by this means the same machine may be used for making nuts of various sizes and shapes. Two of these machines have now been at work at the writer's works in Manchester for upwards of five years. With the aid of a good furnace, from 15 to 20 cwts. of $\frac{7}{8}$ or 1 inch nuts can be produced in a working day of 10 hours, the machine running at 60 revolutions per minute. All the nuts possess the same degree of accuracy in shape, the sides being parallel to each other, and the hole being punched perfectly central whilst the nut is under pressure in the diebox. The iron is fed into the machine at a welding heat, and the pressure put upon it by the swages in the diebox has the effect of closing up the fibres of the iron, as seen in the samples exhibited, making the nuts very much stronger than those forged in the ordinary way by hand. The holes punched are perfectly clean and regular, and have no scale inside them to injure or chafe the threads of the taps, when being screwed.

A Bolt Heading Machine, similar in some of its principal parts to the nut making machine just described, is shown in Figs. 26 and 27, Plates 70 and 71. Fig. 26 is a general plan of the machine, and Fig. 27 is a sectional plan to a larger scale, showing the arrangement and operation of the dies and the heading swage. The dies A and B, Fig. 27, which enclose the long end of the bolt C to be headed, are divided longitudinally down the centre, one half A being carried by the stationary brackets D, and the other half B by the shearing slide E, to which a reciprocating motion is given by the cam F, Fig. 26. At the outer end of the stationary die A is fixed a steel cutter I of exactly the same form as the die A; and in a similar position in the shearing slide E is a corresponding steel cutter J, projecting for the purpose of cutting off from the bar of iron the length C for making the bolt. The dies A and B are made in short lengths, so that the total length can be increased or diminished by inserting pieces of different thickness, whereby bolts can be made of any length from 1 up to 12 inches; the remainder of the space being filled up by packing pieces, and the whole firmly held together by the bolts G.

The bar of iron for forming the bolt C, Fig. 27, heated to a welding state for a short distance only at the end, and of the same diameter as the screwed portion of the bolt, is inserted between the dies A and B while open, and pushed in up to the heading swage H, the length of which is adjustable so as to measure off the iron to the correct length for making bolts with different thicknesses of head. As soon as the bar is inserted between the dies, the shearing slide E carrying the die B and cutter J being pressed forwards by the cam F cuts off the length C for forming the bolt; the cutter and die B then remain stationary in this position and hold the bolt C firmly between the dies A and B until the formation of the head is completed. The diebox K is now moved forwards by the cams L and slide M, until it touches the face of the dies A B; when immediately the centre ram N carrying the heading swage H is advanced by the cam O, and compresses the heated metal so as to fill the diebox K and form the bolt head. The heading swage H then remains stationary whilst the diebox K is drawn back clear of the bolt head, when the swage also retires to its original position. The shearing slide E is then withdrawn by the cam F, leaving the bolt C in the stationary half A of the dies; and a knocker P actuated by a cam at the side of the large wheel R, Fig. 26, strikes the finished bolt, and discharges it from the dies.

This machine makes about 30 strokes per minute, and is capable of producing a bolt at each stroke, provided it be supplied with the iron at a proper heat. The bar of iron is heated only at that portion which is to form the head, the remainder or bolt end being cut off cold. The object of this is to prevent the bolts from being scaled their whole length through the action of the fire. Some sample bolts made by one of these machines are exhibited to the meeting. The ram N carrying the heading swage H is acted upon by the cam O through the intervention of a lever S, through which the whole pressure is transmitted; and the bottom end of this lever is centred upon an oak beam fixed inside the framing of the machine, which being slightly elastic prevents the machine from being broken in the event of more iron being inserted into it than is required to make the bolt head. In consequence of this provision a bolt has been made without breaking the machine with a head as much as $1\frac{3}{16}$ inch thick, when the dies were set to make it only $\frac{3}{4}$ inch thick: this bolt is also exhibited to the meeting.

There are a great variety of special tools, for railway and machine-making purposes, which the writer has been obliged to pass over, and which would form ample material for another paper.

In conclusion it may be remarked that the opinion is now universal that, without extraordinary strength, rigidity, and power in tools, their work cannot be accomplished either quickly or well. Accuracy in the manufacture of tools and their universal application have had a great effect in the perfection of the work executed and in the facility and economy of its performance. By the assistance of gauges for different parts of machinery, the advantages of engineering tools have been more fully realised; and no engineering work of whatever magnitude need now remain unaccomplished for want of tools.

Notwithstanding the length of time during which the improvement of tools has been in progress, and the great advance that has been made, it may be said that at the present time there is a wider field for improvement than ever, and a constant and increasing demand for tools of novel construction for special purposes.

The **PRESIDENT** remarked that they were greatly indebted to Mr. Fletcher for his very interesting paper just read, which had been kindly prepared by him, as one of the oldest manufacturers of heavy engineering tools in the country, in compliance with the special request of the Local Committee, for the occasion of the present meeting of the Institution in Glasgow.

He enquired respecting the nut making machine described in the paper, what quantity of nuts was produced by the machine in regular work before the punch and diebox required facing up again, and whether the punch and diebox did not get hot in working.

Mr. **FLETCHER** replied that the punch and die generally required facing up about once a day, and lasted about six or seven months in almost constant use before requiring to be replaced: they produced on the average about a ton of nuts without facing up. A large jet of cold water was kept constantly playing upon the punch to prevent its becoming hot; and with the machine running at the speed of 60 to 70 revolutions per minute, the time that the heated metal was in the diebox was so short that it scarcely produced any effect in heating the dies. At first the machine had been run at 30 to 40 strokes per minute, but the speed was afterwards increased to 50 and then to 70 revolutions per minute, as it was found the faster it was driven the better was the diebox kept from heating. Beyond 70 revolutions per minute however he did not think the workman could keep up with the feeding, which had to be learned by practice, the same as in working other machines running at high speeds.

The bar of iron from which the nuts were made had to be turned over at each time of feeding, because the diebox in shearing off the piece of iron to form the nut bevilled the edge of the iron a little; but by turning it over each time the bevil was reversed for the next nut, and the nuts were thus made all sound and solid throughout without any deficiency of metal or any imperfect places upon the external surfaces. The workman soon became expert by practice in turning the bar of iron and feeding the machine with perfect regularity up to the speed of about 70 revolutions per minute.

The PRESIDENT enquired whether the common iron was found good enough to make nuts from by the machine.

Mr. FLETCHER exhibited some specimens of the nuts made by the machine from common iron, which had been split open afterwards by a taper punch for the purpose of showing the nature of the fracture, and it was seen in all of these that the metal was closely compressed and condensed and made thoroughly sound in the process of forming the nut. The hot iron blank was confined in the diebox and compressed by a heavy pressure during the operation of punching out the bolt hole, and it was found that by this means the nuts made by the machine from common iron were as strong as nuts made from best iron punched in the ordinary way. Some of these nut making machines had now been at work in Glasgow for several years.

Mr. W. MCLELLAN said he had two of the nut making machines now at work, which had been working regularly for about two years in Glasgow, and were found to answer very well indeed. In first beginning to work them, the machines had been driven at only about 50 revolutions per minute, as it was feared the workman would not be able to feed at a higher speed: afterwards however the speed was increased to 60 revolutions per minute, at which the machine was found to work better; the tools lasted longer, without so many breakages as at the lower speed of 50 revolutions. With regard to facing the dies, he had found they would work considerably longer than had been stated before requiring facing up, for the machines at his works had turned out as much as 2½ tons of nuts each with one set of dies without facing up.

Mr. J. **Kennan** enquired what metal the dies were made of in the nut making machine, whether steel or chilled cast iron.

Mr. **Fletcher** replied that he had used chilled cast iron, malleable cast iron, and steel for the dieboxes, and had found that ordinary cast iron chilled was about the best material for the purpose; the swages and punch working through the diebox had never been made of anything but steel.

Mr. H. **Maudslay** remarked that the gradual introduction of drilling machines during the last few years for making the rivet holes in plates of girders and bridge work generally, in place of punching them as formerly, appeared to be attributed in the paper just read to the defective character of the work performed by the punching machine, and the difficulty of getting a good joint with two punched plates rivetted together. This however he thought was not the case; and when it was considered that the punching machine, since its invention as a self-adjusting and self-feeding machine by the late Henry Maudslay some forty years ago, had been increasingly employed for all rivetted work, and had been adopted for iron shipbuilding purposes in all the dockyards in the country, while it was also employed at the present time in the manufacture of steam boilers for working at pressures up to 250 lbs. per square inch, he thought the modern practice of drilling the rivet holes for bridge work could not be accounted for by the workmanship produced by the punching machine being inferior. The real reason he believed was to be found in the circumstance that in ordinary boiler work there were only two plates to be rivetted together, with a lap joint, and the rivet holes were all along the edges of the plates; but in the present construction of large plate-iron girders, where the thickness of the girder was made up by four or five plates rivetted together with butt joints, the plates were arranged to break joint with one another, so that there should not be more than one butt joint at any one place; and consequently the rivet holes came in all positions in the plates, from the edges to the centre, and no punching machine that had ever been made would be large enough to take in all the plates, for punching through all the thicknesses simultaneously, nor could the plates be punched separately with sufficient regularity in the position of the holes for enabling them to come together afterwards with the perfect accuracy necessary in that description of work. It was therefore inevitable to resort to drilling for that sort of work, in order to have the means of making the holes in any position in the plates, and with such regularity that they should correspond with perfect accuracy throughout the whole series of plates.

Mr. **Fletcher** explained that in alluding to the defective workmanship of punching machines for making rivet holes he had referred only to the case of wrought iron bridge building, where girders were composed of a number of thicknesses of plates rivetted together. If punched holes were employed in that description of work, they were inevitably made slightly tapering by the process of punching; and when five or six punched plates were brought together for rivetting up, the rivet could only be made to fill the holes in the two outside plates, and merely passed through the inside plates, without touching them except just at the smallest part of the hole. For ordinary boiler making and similar purposes, where there were only two plates to be rivetted together, it was perhaps possible that punched holes might make a stronger joint than drilling, if care was taken to punch the holes the right way and then put the plates together with the small ends of the holes next to each other; but even then the holes would not be any better filled by the rivets than they would be if made by drilling, and drilling gave the means of filling the holes completely by the rivets through any number of plates that had to be put together. But as to injuring the quality of the iron round the hole, there was no doubt that punching must do so to some extent, by the splitting strain put upon the metal by the punch; and this was clearly shown by cutting open plates rivetted with punched holes and with drilled holes, when the difference in the state of the metal round the holes in the two cases was plainly seen.

The **President** enquired whether any difficulty had been found in the multiple drilling machine, from the drills not working equally after they had worked a length of time, and thereby not drilling the holes with the required accuracy in the plates.

Mr. **Fletcher** replied that there had not been the slightest difficulty from that cause, and the whole of the work done by the drilling machine was so uniform that the plates were put together indiscriminately with perfect accuracy. He had seen a girder some time ago at Messrs. Kennard's works at Crumlin, in which there were four thicknesses of plate in the flanges and six thicknesses at the joints, all with holes drilled by one of these machines, put together ready for rivetting up; and in walking over a length of 200 feet along the top of the girder with an iron rod turned to the size of the drilled holes, he had been able to drop the rod easily through all the four or six thicknesses of plates at every hole that he had tried. The saving of time therefore in putting such a girder together and rivetting up must be very great indeed as compared with a girder constructed of punched plates. In making the holes in the plates he did not think there would be much difference in time between punching and drilling; and in respect of cost, probably drilling would be cheaper than punching, where there was a large quantity of work to be done and a set of men properly trained to it. There could be no question therefore, he considered, that in bridge work especially drilling was far superior to punching for the rivet holes. In the multiple drilling machine shown in the drawings, the plates to be drilled were placed on a stage close by the machine, ready to be slided upon the drill table; one man and a boy attended the machine, and put the plate on and removed it when drilled. During the drilling the plate was entirely immersed in soap and water, in which the drills worked; and if anything went wrong, the drill table was let down immediately by shutting off the water pressure from the accumulator, and was afterwards raised up again to its work with the greatest readiness by turning on the pressure again.

Mr. J. **Vernon** remarked that at the Liverpool meeting of the Institution in last year he had exhibited some specimens of plate that had been rivetted together with punched holes and with drilled holes, and had been afterwards cut open down the centre of the rivets so as to show in both cases how the rivets filled the holes; and it was then clearly seen that the rivets filled the punched holes as perfectly as they did the drilled holes. From his own experience also he fully concurred in the opinion that it was not because work was unsound and imperfect when done with punched holes that drilling was required to be resorted to: drilling had its advantages and might be largely applied; but it was not the case, he believed, that punched work when carefully prepared was imperfect or inferior work. With respect to accuracy in the position of the holes, he thought as great accuracy might be attained with punched holes as with drilled holes; and he had had a punching machine in operation at his own works for several years past, which was capable by a self-acting motion of punching a whole boiler plate throughout every part with as complete accuracy as could be attained in any drilled work that could be produced.

Mr. D. **Adamson** observed that, having had frequent opportunities of witnessing the testing of high pressure steam boilers, sometimes with punched rivet holes and sometimes with drilled holes, he had come to the conclusion that no one who had had experience of drilled holes in that particular class of work would be likely to attempt to use punched holes again for such purposes. However carefully a punching machine might be arranged, and however well the work might be put together, there still remained the objection which had been mentioned, that the punched holes were always conical, rendering it a difficulty to fill the holes completely in hand rivetting. Several boiler explosions which he had seen might be entirely attributed, he believed, to that class of bad work. In the case of an explosion that occurred some years ago at Huddersfield, he had examined the boiler afterwards, and had not found a single instance in which the rivet filled the rivet hole completely from one side of the plate to the other, and there were very few rivet holes that were at right angles to the plates, the rivetting being exceedingly bad and the punching exceedingly bad also. In punching holes too much depended on the care exercised by the workman, and he had found that boiler plates punched on Monday were not done so well as those punched later in the week, from the men not being so careful and accurate on the first day of their week's work as they were afterwards when they had got more into it. It was therefore very desirable to take it out of the power of the men to produce defective work; and he had accordingly adopted the plan of not only drilling the holes in all boiler plates that were to be subjected to a high pressure, but also drilling the two plates together in the position in which they were to be rivetted up, in order to allow correctly for the curvature of the plates; so that it should be impossible for the workman to produce irregular holes, and that when the plates were rivetted together all the holes should coincide exactly, and every rivet should take its proper share of the strain.

In the case of the longitudinal seams of large boilers, say 6 feet diameter made of 9-16ths inch plates to carry 100 lbs. steam, he considered the single rivetted joint with punched holes was exceedingly unsafe on account of the great shearing strain to which the rivets were subjected. Moreover although in a single test such a boiler might appear tight up to the testing pressure, it would be found that by afterwards raising the pressure again rapidly up to the testing amount the joints would not be tight in the second test, but would exhibit a slight leakage or sweating in many places, which would be continued and increased in any subsequent testing when the pressure was raised quickly. It was therefore not sufficient to try boilers by a single test, but a prolonged trial was necessary, repeating the test say fifty times in a day with intervals; and having adopted this mode of testing he had found that, in testing punched boilers for a day together, every time the pressure was put on there was more or less trickling from the joints; but with drilled holes the work was much more to be depended upon, and there was less of the ordinary sweating at the joints, nor was any serious leakage ever produced by repeatedly putting up the pressure rapidly. Hence for locomotive boilers especially, subjected as they were to such rapid variations of pressure, it appeared highly desirable that all the rivet holes should be drilled, and also that the two plates should be drilled both together in the position in which they were to be rivetted.

In boilers of very large diameter, such as 7 feet diameter with plates ¾ inch thick, single-rivetted joints became impracticable, whether the holes were drilled or punched; because the extra thickness at the lap of the joint threw the plates so much out of the true circle that every time the pressure came upon them it sprung the joint with a force which inevitably produced leakage when only a single row of rivets was used. No doubt a great deal of the external corrosion observed in boilers was due to the continual small leakages produced in this way by the variations of pressure. But a more serious evil, especially in locomotive boilers, was that this constant springing of the joint had ultimately the effect of exfoliating the interior surface of the plates all along the seam; and the iron became guttered along the edges of the plates to such a depth through the thickness of the metal that in some cases locomotive boilers had exploded whilst working at no higher than the ordinary pressure.

It was true that in rivetting up punched work with the steam or power rivetting machine the rivets might be made to fill the holes, but it did not follow that work so put together was as strong as if the holes had been drilled; for on planing open the joint in the punched work it would be found that there was more or less irregularity in the holes, and therefore the rivets would not all of them take their proper share of the strain along the whole length of the joint. But when drilling was used and all the holes were drilled exactly at right angles to the plates, and when the rivets were made in accurate dies so as to contain all the same amount of metal, and were afterwards put in the holes by a power rivetting machine, a joint was ensured which probably no rivetting would be able to excel. So satisfied was he of the advantages of drilling over punching, in the greater security and tighter work obtained with drilled holes, especially in the case of boiler work, that he hoped in a short time to carry out drilling exclusively at his own works, and to abandon punched holes altogether for any description of work whatever. A still further step remained in reference to the longitudinal seams of boilers, which would be to weld up the plates along the joint, so as to avoid having any rivetted joint for such cases; and he had been led to conclude that this would prove the only ultimately satisfactory plan, as he considered more confidence was to be placed in the welded joint than in the best rivetted joint even with drilled holes.

Mr. T. Fleet considered that, when punching was done carefully and accurately, as good and sound work could be produced with punched holes as with drilled holes. It appeared to be thought that in drilling there was not so much liability to want of uniformity in the holes as in punching; but in the multiple drilling machine shown in the drawings, if the drills were not all set perfectly true in their correct positions and exactly upright, the drilled holes would be no more regularly spaced and no more truly at right angles to the plates than punched holes done by a good workman. Moreover if the drills were not properly looked after by the man attending the machine, he might as easily cause defective work to be turned out as a man setting plates in a punching machine. No doubt workmen were apt to be not so efficient at their work in the beginning of the week as afterwards; but that was a matter which rested with the masters and foremen, and no work of an inferior description ought to be allowed under any pretext. It was certainly the case that in punched holes there was a little taper; but by properly proportioning the size of the punch and of the hole in the die, the degree of taper might be reduced to so small an amount as not to be injurious; and if two punched plates were put together with the smaller ends of the holes next each other, the work would be made as good as it was possible for it to be. He had had rivetted joints planed through down to the rivets for the sake of trial, and had found the punched holes were as well filled by the rivets and the work was as good and sound as when the holes were drilled. It was only within the last few years that the question of drilling the holes for boiler plates had been raised; and for many years previously boilers with punched holes had been made tight and fit for service, and were still made so, nor had he known of an explosion occurring with any boilers made with properly punched holes. As regarded rivetting more than two thicknesses of plates together in bridge work, which had been said to be not so safe with punched holes as with drilled holes, he had not found any deficiency of strength with punched holes, even in rivetting as many as four or five thicknesses of plates together up to a total thickness of $3\frac{1}{2}$ or 4 inches; and in all such cases the work so put together with punched holes had stood the testing without any difficulty, and had proved thoroughly sound and strong for the purposes intended.

In reference to the use of steam rivetting machines for putting in the rivets instead of hand rivetting, that question had been considered at the time of building the Britannia Bridge, in the rivetting work of which he had been engaged; because it was then thought that hand rivetting would not be sufficiently good for that class of work. Wrought iron bridge building being then in its infancy, a trial was made of the comparative value of the machine rivetting and hand rivetting, by cutting out a number of rivets put in by the two methods; and it was found that in the work done by the steam rivetting machine the holes were not filled up so well as by hand rivetting, and the rivets put in by hand took about ten or twelve more blows to knock them out with the hammer than those put in by the machine: the bridge was accordingly completed with hand rivetting. Moreover in rivetting by machinery, both in boiler making and in bridge work, if the plates were not brought perfectly close together at the time of rivetting, when the blow came on the rivet it formed a sort of washer between the plates, which prevented their ever being closed up afterwards; but in hand rivetting a good rivetter took care to drive the rivet fairly into the hole and close the plates with the hammer at the same time that he was finishing the rivet, so that the contraction in cooling should make a perfectly tight joint.

The **President** enquired how the spur mitre wheels driving the drill spindles in the multiple drilling machine were found to wear, and whether malleable cast iron had been tried for the purpose.

Mr. **Fletcher** replied that these spur mitre wheels were found to wear very well indeed; he exhibited some of them made of cast iron, which had been working constantly in one of the drilling machines ever since it was started nearly twelve months ago, and they scarcely showed any signs of wear at all. Some of the wheels on the horizontal driving shaft had been broken occasionally, in consequence of having the centre hole too large; these had broken through just at the key groove, owing to the drill happening to break just at the moment of going through the plate, which was liable to occur now and then. He had tried malleable cast iron for the wheels, but found it would wear too fast; and the wheels were now made therefore of cast steel, of which specimens were exhibited, in order to obtain greater strength, and he had never had any of the cast steel wheels broken in the machine. When only a single horizontal driving shaft was used, having some 50 wheels keyed on it for driving the drills, the torsion was of course very great, and a large diameter of shaft was required to give sufficient strength; but by the improved plan of using two horizontal driving shafts, driving the alternate drill spindles, each shaft had only half the work to do, and a smaller size of shaft could therefore be used. The shafts were made of cast steel, and he had also driven each shaft at both ends; but the torsion was still considerable in the middle of the length, and caused the skew wheels to rattle a little in working, as the drills cut harder or easier in the metal.

Mr. J. J. Birckel enquired why the skew mitre wheels employed in the drilling machine had been applied for driving the drill spindles in place of ordinary mitre wheels. He thought there must be much more friction with the skew wheels than with ordinary mitre wheels, since in the latter the friction was more of the nature of rolling friction.

Mr. Fletcher explained that the object of adopting the skew wheels instead of ordinary mitre wheels for driving the drill spindles had been that the horizontal driving shaft might be kept out of the way, behind the drill spindles, so as to allow of getting a good strong tail piece with set screw at the top of the drill spindles, for receiving the heavy upward pressure on the drills in working. This could not have been managed with mitre wheels and the longitudinal shaft overhead.

Mr. J. Kennan enquired whether there was not some difficulty from the end pressure on the horizontal shaft driving the drill spindles, owing to the inclination of the teeth of the skew wheels; and he suggested that the teeth might be inclined at opposite angles alternately right and left in the successive wheels, so as to neutralise the end pressure on the driving shaft.

Mr. FLETCHER said there was no end pressure at all on the horizontal driving shaft, as each of the skew wheels on the shaft worked between two end bearings in its own drill frame, which received the end pressure instead of the shaft.

The PRESIDENT enquired whether the parallel motion was found to answer satisfactorily the purpose of keeping the drill table level in working.

Mr. FLETCHER said the parallel motion formed by the pair of racks and toothed segments coupled together at each end of the drill table had been found a great improvement in the multiple drilling machine. Previously it had been necessary to place a block of wood on each side of the drill table, as a stop to limit its height of rising and prevent it from canting in case the drills on one side of the machine should come through the work sooner than those on the other side. But with the addition of the parallel motion there was not the slightest deviation from level in the table, either sideways or endways, at whatever part of the table the pressure of the drills might be acting; and it was thus of great advantage in preventing any undue pressure from some of the drills getting through the plate before others.

Mr. J. KENNAN asked whether any trials had been made with different forms of drill points, and what form of point had been found the best.

Mr. FLETCHER replied that he had tried several forms of drill points, but found there was the least trouble with the ordinary shape of point, such as was shown in the drawings and in the specimens of drills now exhibited. The speed of drilling might be increased by putting extra pressure on the drills, and by that means he had drilled through $\frac{3}{4}$ inch plates in as little as $3\frac{1}{2}$ minutes; but this rate was not necessary in ordinary work, and such plates generally took about 10 minutes to drill through.

Mr. W. M. NEILSON enquired whether the drills were ground up by hand, and how the grinding was done so as to keep them all uniform.

Mr. Fletcher replied that the drills were all ground up by hand to a gauge, so as to be all exactly the same diameter and form. The drills were carried in cylindrical sockets and fixed by set screws, allowing of their being adjusted to a constant length when shortened by grinding. At Messrs. Kennard's works at Crumlin there were six of the large multiple drilling machines, and two smaller ones, and one man was employed in grinding up the drills for the whole of the machines, to keep them all uniform.

Mr. W. Richardson enquired whether there was not some difficulty with the drilling machine at the moment of the drills going through the plate, on account of the drill table being forced up against the drills by the constant pressure of the accumulator. He thought when the drills were just going through, the table would rise too fast, and be apt to break the drills by the side strain put upon them from suddenly losing the resistance of the cut.

Mr. Fletcher said that when the drills were beginning to come through the plate the workman could hear it directly, and could ease off the water pressure a little if desired, by partly closing the valve from the accumulator: but it was scarcely ever necessary to do that, and there was very little trouble from the drills breaking at the moment of going through. The drills were made pretty stiff, and very short from the bearing in the drill socket, so as not to be easily broken.

Mr. W. Ford Smith asked how the drill spindles were set in the machine with sufficient accuracy at the exact distance or pitch from centre to centre. In the case of the transverse joints of cylindrical boilers, for instance, the outer plate lapping over the inner was of course a little longer; and having the same number of rivet holes would require the holes spacing rather wider apart all round the circle, so as to correspond with the holes in the inner plate. It had been proposed to drill the holes in the two plates together for boiler work; but though that might be done for the longitudinal joints, it could not be managed in the transverse joints from the difference in the length of the two plates.

Mr. Fletcher explained that the drill spindles were all turned accurately to 2 inches external diameter at the bottom or drill socket, and were set up one after another by inserting a template of the required size between. Thus for drilling holes at 3 inches pitch a template of exactly 1 inch width was put between the drill spindles; and supposing this were the pitch for the rivet holes in the inner plate of a transverse boiler seam, and the outer plate were 1½ inch longer, the extra 1½ inch was divided out equally between the entire number of holes by using a slightly larger template made to the exact size required. As there were two rows of drills in the machine, the best plan in such work was to set one row for drilling the inner plates and the other for drilling the outer plates, so that the drilling of both plates should be proceeded with simultaneously.

Mr. D. **Adamson** thought that plan would still not be so satisfactory as drilling both the plates together, as they were to go in rivetting; and even in the case of the transverse joints of boilers it was highly desirable that this should be managed, by bending the plates beforehand and then drilling them together solid when bent, so as not to have to disturb the iron in any way by bending after drilling. The great advantage of such a method was that the very same drill passed through both plates, and therefore any slight variation in the size of the drill used did not affect the accuracy and solidity of the work for rivetting up, and the hole was perfectly cylindrical through both plates. This could not be said however of plates drilled separately while flat and afterwards bent to the required curve.

Mr. **Fletcher** had not found any inaccuracy arise from drilling the plates separately instead of together, or from bending the plates after drilling them flat. In plates 5-16ths or 3-8ths inch thick the alteration in the holes by bending the plates after the drilling was so inappreciable that a turned pin could be passed through the holes in such work with as great facility as in the case of the flat plates drilled for bridge work, which he had already mentioned. He therefore thought drilling the plates together after bending was scarcely necessary for practical purposes.

Mr. J. **Manning** said he was now making a self-acting punching machine for punching flat plates independent of manual labour, with an adjustable rack motion for shifting the plate and spacing out the holes, and a variable curvilinear movement for punching the circular lines of rivet holes in the end plates of boilers for the shells or the internal flues. A dividing scale was also added for making the proper alteration in the pitch of the holes in the outer and inner plates, in punching the rivet holes for the circular seams of the boiler shell. He was not aware whether this had been managed yet in punching machines, and thought if successfully carried out with the required degree of accuracy it would go far towards removing the objections entertained against punched boiler work.

Mr. J. **Vernon** enquired whether the use of separate engines, one to each machine, for driving a number of separate machines doing a variety of work, as in the case of iron shipbuilding, was considered to be under all circumstances a more advantageous and economical application of steam power than driving the same machines by a line of shafting and belts. Supposing there were a dozen large machines in the same workshop, which were all required to be worked constantly the whole day through, he presumed it would not be considered better in that case to use separate engines for each machine than to employ one engine for driving the whole lot of machines by shafting.

Mr. **Fletcher** said that in the latter case, having a number of machines that were all kept constantly at work, and where the work could be kept close to the machines without having to be frequently taken out of the shop and brought back again, the single large engine with shafting to drive all the machines was no doubt the best. But whenever, in the case of shipbuilding and similar work, it occurred that plates had to be carried backwards and forwards a considerable distance, merely for punching a few more holes or doing some other small work upon them, it was then found much better and cheaper to take one or two machines down to the spot and do the work there: and it was for such purposes as these that machines were now made to be driven each by its own separate engine.

Mr. **Neil Robson** enquired whether any difficulty was found in conveying the steam to a distance for working separate machines, owing to leakage at the joints of the steam pipe. He had himself found great difficulty in keeping the joints tight, particularly in one instance where the steam was conveyed as far as 400 yards in a straight line of pipe, in which case he had got over the difficulty by making two expansion joints in that length: and he asked what was the greatest distance to which steam had been conveyed from a boiler for working an engine or machine.

Mr. FLETCHER replied that the difficulty with the joints of the steam pipe in such cases arose from having the pipe in a straight line for the whole distance, without any curves; but if there were a few curves inserted in the length of the pipe, these would allow for the expansion and contraction of the line of pipe, and there would be no difficulty in keeping the joints steam-tight. Any condensation of steam that took place in the pipe might be provided for by having a low part in the pipe at the further end, with a tap to draw off the condensed water whenever desired.

Mr. D. ADAMSON said that, in regard to the distance to which steam could be carried in pipes, there was not much difficulty in conveying it even to very great distances. At one of Mr. Joseph Pease's collieries near Darlington, where the whole of the water was originally pumped by engines at the surface, it was afterwards desired to work a lower portion of the mine, for which purpose a pumping engine was placed down in the pit, and was at first supplied with steam by boilers alongside in the pit. The water pumped from the mine however was so corrosive and destructive to the boilers in the pit, that it was ultimately found necessary to abandon them and to take steam from the boilers at the surface. The distance the steam had to be conveyed by pipes in that instance was very great indeed: the pit was about 120 yards deep, and the underground engine was about $\frac{3}{4}$ mile from the bottom of the pit, making altogether about 1440 yards distance that the steam was carried; notwithstanding which the work done by the engine per pound of coal consumed under the boilers was very nearly equal to what it had been when the boilers were down in the pit close to the engine. It appeared therefore there was no reason to anticipate any difficulty in merely distributing steam by means of pipes to the comparatively short distances necessary for working detached machines in a shipbuilding yard or similar cases. In the instance that he had described, a large branch syphon pipe was connected to the steam pipe at the further end, close to the engine, in which the condensed water collected and was drawn off at intervals, while the steam passed along the straight pipe direct into the engine.

Mr. J. J. Birckel mentioned that in preparing the plates for the construction of the Great Eastern ship the edges of the plates had not been planed, but shaped in a circular shaping machine which he believed was similar to a facing lathe.

Mr. Fletcher said he had made a number of machines of that description for shaping the edges of plates instead of planing them in an ordinary planing machine. The machine had a large disc about 6 feet diameter, revolving on a horizontal shaft, and in the face of the disc were fixed a set of about 36 cutters, across which the plates to be shaped were traversed on a horizontal sliding table. Three of these machines were at work at the Crumlin Works, where they were employed in shaping the edges of plates, instead of planing them by the planing machine as usual.

The President remarked that he had had disc machines of that description in operation at his own works for the last thirty years, and they were used for cutting the inside of sheer strakes in shipbuilding and for similar purposes. He enquired which plan was considered the best, the disc machine or the ordinary planing machine.

Mr. Fletcher replied that where there were a great number of plates to be shaped to the same size or pattern, as in bridge work or shipbuilding, he thought the circular disc with cutters would be found more expeditious than a planing machine. For with the disc machine a number of plates could be clamped together and brought up on a truck and laid on the table of the machine, which could then be left to do the work with only a boy to mind it for two or three hours; but with a planing machine the men were continually occupied in bringing up one or two plates to be planed at a time. By means of the disc machine, as much as 3 feet thickness of plates had been shaped at once in the case of the plates for the Great

Eastern; and the machines at Crumlin shaped 18 inches thickness of plates or upwards in ordinary work.

Mr. W. **Ford Smith** remarked that the angle of 85° adopted for the V grooves in the tables of planing machines appeared to him rather more acute than was desirable or necessary, since the friction was of course greater with an acute angle than with one more obtuse, requiring therefore greater power to drive the table with the acute Vs; and it was also desirable, in order that the Vs might keep in good order, to get as wide a bearing surface as possible, so as to reduce as far as practicable the pressure per square inch and consequently the friction and liability to galling. He had accordingly adopted a considerably wider groove for such purposes, with an angle of 120°; and he had not found any difficulty from the table of the machine ever rising up the sides of the Vs made with that inclination, and thought the surfaces of the grooves wore better than if made more acute. For oiling the Vs the ordinary plan was to fill the channel at the bottom of the groove with oil, which was then raised by agitators and spread over the sides of the groove by the motion of the sliding table; but as any dust and cuttings falling into the grooves would collect in the channel at the bottom and be mixed with the oil, he thought it was better to oil the grooves by a channel at the top along each side of the groove, filled with pure oil by self-acting lubricators, by which a small quantity of oil would be caused to flow over down the sides of the groove; and the oil should be swept off into pockets at the ends of the Vs by each traverse of the table, instead of being allowed to lie in the bottoms of the grooves. By this plan combined with the increased surface of wider Vs there would be less liability to the surfaces galling in working.

With regard to the use of the rack motion for sliding the table in planing machines, no doubt the use of the pinion of large diameter gearing into the rack was a great improvement in principle upon the ordinary small pinion, since with the large pinion there was less tendency to lift the table. But in reference to the employment of stepped teeth for the rack and pinion, in place of the ordinary single teeth, he had not found it practicable to produce castings of stepped racks and pinions so accurately spaced throughout as to ensure all the teeth taking their proper share of the work; the whole strain of the driving power, instead of being borne by the entire width of the rack, had consequently to be borne only by the portion of the width that happened to be actually in contact, and hence breakages were liable to take place. He had accordingly been led to adopt plain racks, not stepped, with pinions of large diameter, for traversing the tables in planing machines and similar cases; and the results had proved thoroughly successful, not only in preventing breakages, but also in producing good planed surfaces, perfectly free from jars and teeth marks.

Mr. FLETCHER said that with regard to the angle of the **V** grooves in the planing machines he had not found any tendency to galling of the surfaces with the inclination of 85° that he had adopted; one machine that he had made twenty years ago with **V**s of that angle had been doing work of the heaviest and roughest description ever since at Messrs. Napier's works, and he had no doubt it would be found on comparison that the surfaces of the grooves were now in better condition than would be the case he believed in any machines with wider **V**s after working for the same length of time. The plan that had been mentioned of oiling the **V**s by a channel of oil at the top, along each side of the groove, had the objection that the machine would then require oiling many times in a day; whereas with the ordinary plan of oiling, by keeping the supply of oil in the bottom of the **V**, the machine need not be oiled more than once in three or four days.

In reference to the stepped rack for driving the tables of planing and other machines, he believed the rack motion was more generally used for such purposes than the screw, and he had adopted the rack exclusively for the last twenty or thirty years as the most eligible arrangement; nor had he found any such difficulty as had been referred to in practically attaining sufficient accuracy in the teeth. He was confident that if any well made machine worked by the stepped rack motion were examined only a couple of hours after it was first put to work, before it had even completed planing its own table, it would be found that all the teeth had got into efficient driving contact.

The **President** moved a vote of thanks to Mr. Fletcher for his paper, which was passed.

The following paper, communicated through the President, was then read:—

ON THE PRINCIPAL SEAMS OF COAL AND IRONSTONE IN THE GLASGOW COALFIELD.

BY MR. WILLIAM MOORE, OF GLASGOW.

General description of Coalfield.—The valuable seams of Coal and Ironstone in the Glasgow Coalfield are situated in the counties of Lanark, Stirling, Dumbarton, Renfrew, and Linlithgow, and lie between the New Red Sandstone and the Hurlet Coal. They are divided into an upper and a lower series of minerals: those seams lying above the Garnkirk or Caulm limestone of Garnkirk and Bedlay form the upper series; and those lying under the Possil ~~or~~ Cowglen limestone form the lower series. The accompanying plan, Fig. 1, Plate 72, shows the general outline and position of the Glasgow coalfield. The dark shade shows the area of the thick seams including the Splint coal and the seams above it; and the light shade shows the limit of the coalfield and the ironstone field. No portions are shown on the plan of the other adjoining coalfields of Ayrshire and Fifeshire. The positions and names of the principal coal districts are marked upon the plan within this area.

The general average section, Fig. 2, Plate 73, shows the succession of the seams from the surface, which are enumerated in the accompanying table. From this section, it will be seen that the most valuable seams of coal lie above the Garnkirk or Caulm limestone in the upper series; and that the principal seams of ironstone lie under the Possil limestone in the lower series of minerals. It is from the upper series that the coals have been taken for the supply of household, manufacturing, and ironsmelting purposes, during almost the whole history of the coalfield; and the principal seams in this series are collectively known as the Glasgow and Monkland seams, extending over an area comprising about 37 square miles, more or less interrupted by faults, bounded by

Name of Seam.	Thickness. ft.	in.		ft.	in.
UPPER SERIES.					
Palacecraig Blackband Ironstone	1	0	to	1	6
Upper Coal	4	0	to	5	0
Ell Coal	2	0	to	11	0
Pyotshaw and Main Coals	4	0	to	9	0
Humph Coal	2	0	to	2	6
Splint Coal	2	6	to	5	0
Wee Coal	2	0	to	2	6
Musselband Coal				2	5
Airdrie Blackband Ironstone	1	0	to	1	5
Soft Blackband Ironstone	3	0	to	6	0
Cleland Rough Clayband Ironstone				1	0
Virtue Well Coal	2	0	to	3	0
Bellside Blackband Ironstone		6	to		10
Kiltongue Coal	2	0	to	6	6
Drumgray Coal	1	8	to	2	6
Lower Drumgray Coal	1	4	to	2	0
First Slaty Blackband Ironstone		7	to	1	7
Second Slaty Blackband Ironstone		8	to	1	3
Third Slaty Blackband Ironstone		7	to	4	0
Roman Cement	1	6	to	2	2
Garnkirk or Caulm Limestone	4	10	to	7	0
LOWER SERIES.					
Possil or Cowglen Limestone	4	3	to	5	0
Possil Upper Coal	2	0	to	3	1
Upper Possil Ironstone	1	0	to	1	2
Possil Main Coal	1	7	to	2	6
Lower Possil Ironstone		9	to		10
Lesmahagow Gas Coal	1	0	to	1	8
California Clayband Ironstone		9	to	1	2
Garscadden Upper Blackband Ironstone		8	to	1	2
Garscadden Lower Blackband Ironstone		4	to	1	2
Garibaldi Clayband Ironstone		11	to	1	6
Dalry Blackband Ironstone		10	to	1	6
Smithy Coal	2	6	to	4	0
Limestone	3	0	to	8	3
Limestone	4	0	to	7	2
Hosies Limestone		9	to	6	0
Crossbasket Clayband Ironstone				1	6
Hurlet Limestone	1	10	to	4	0
Hurlet Alum Shale				3	4
Hurlet Coal	5	0	to	6	0

Bathgate and Morningside on the east, by Carluke, Hamilton, and Quarter on the south, by Glasgow on the west, and by Gartsherrie and Jawcraig on the north.

The main supply of ironstone for the use of the Scotch ironworks comes from the two Possil ironstones, the two Garscadden Blackband ironstones, and the Dalry Blackband ironstone. These extend over the district of country indicated by the light shade on the general plan, Fig. 1.

Detailed description of Coal Seams.—The Upper coal, the first in the section, Fig. 2, is that from which Glasgow was in former years supplied with the best quality of household coal. This seam is in its best condition both in thickness and quality near Glasgow, Rutherglen, and Stonelaw. It gradually gets inferior as it goes eastward, and thins out altogether in the mineral fields near Coatbridge and Baillieston.

The Ell coal is the seam from which at present the largest quantity of coal for household purposes is derived, and which now contributes so largely to the supply of Edinburgh, Glasgow, and the north of Scotland. The most valuable deposit of this seam is in the neighbourhood of Wishaw and Motherwell, extending along the line of the Caledonian Railway nearly as far as Carluke, and on the line of the Lesmahagow branch within a short distance of Auchenheath. The thickness of the seam, which is not more than 4 feet at Glasgow and 2 feet at Baillieston, gradually increases towards Wishaw to about 11 feet. In the district adjoining Wishaw the quality is of the first class, and the coal is used chiefly for household purposes. In some of the collieries to the east of Wishaw the coal is of a slightly burnt description, and is used for steam purposes. There is still a considerable area of this seam to work, lying on the line of the railways already mentioned; in the locality immediately adjoining Wishaw however it is very much exhausted. So great has been the demand for this quality of coal for household and steam purposes, that within an area of about three square miles in the Wishaw district there are as many as twenty-five collieries working almost wholly on this Ell coal seam.

The Pyotshaw and Main coals are sometimes apart a distance varying from 6 to as much as 24 feet, as at Baillieston and Coatbridge. At Drumpeller and Wishaw they are together, forming one seam about 9 feet in thickness. The Pyotshaw coal sometimes contains a thin gas coal varying in thickness from 4 to 10 inches: at Springhill near Baillieston this gas seam is of fair quality, and is supplied to the Glasgow gas works. The Pyotshaw and Main coals are hard coals, containing rather too much ash for household use, so that they are used chiefly for ironsmelting and forge purposes.

The Humph coal is a thin seam of not much value. It has been worked at Dalmarnock near Glasgow and at Coatbridge, for furnace purposes and for calcining clayband ironstones.

The Splint coal is that which has been so long used in the manufacture of iron in the Coatbridge district. It is a hard coal of excellent quality, and in the Monkland district is very nearly exhausted. At Wishaw and in the district towards Hamilton it is entire; but it has been found very expensive to work on account of having a soft shale roof. This seam of coal is usually accompanied by a thin band of clay ironstone, varying in thickness from 3 to 4 inches, which is worked in connection with the coal. At Bredisholm near Baillieston this seam becomes a gas coal, and is worked as such to a considerable extent for the supply of Glasgow and for Irish consumption.

The Wee coal is a good household coal, and is extensively worked as such in the Baillieston district for the supply of Glasgow. The collieries working this seam lie principally along the line of the Monkland Canal, by which the coal is conveyed to Glasgow and other parts of the Clyde.

The Virtue Well coal is essentially a Monkland coal. It is found best in the neighbourhood of Airdrie and Coatbridge, and is used principally for household purposes. In some of the collieries near Airdrie the coal is burnt, and is used for steamboat purposes. In the eastern part of this seam extending to Slamannan it is called the Johnstone coal, where it is of a coarser quality and is used for household purposes.

The Kiltongue coal is worked in the neighbourhood of Coatbridge and Airdrie at a thickness of about 2½ feet. At Drumpeller it is 6½ feet thick, and is used for household and forge purposes. In the Redding and Slamannan districts this seam is called the Splint coal; and at Slamannan it is one of the most valuable of the Scotch steam coals, and brings the highest price on the Forth and Clyde for this purpose. At Redding the coal changes its character, and becomes a hard splint coal suitable for iron smelting purposes. Above the Splint coal at Slamannan there is a seam known as the Lady Grange seam about 2½ feet thick, worked chiefly for household purposes. At Calderbraes, in the position which the Kiltongue coal would occupy, there is an ironstone called the Calderbraes ironstone about 8 inches thick.

The Drumgray coal is known in the Redding and Slamannan districts as the Coxrod coal. In the Airdrie and Coatbridge districts this seam is a hard furnace coal; in the Redding and Slamannan districts it is a household coal of very superior quality.

The Lower Drumgray or Lower Coxrod coal is a seam worked for household purposes; it is usually thin however, and is not generally much worked.

Besides the seams above described, which are collectively known as the Glasgow and Monkland seams, there are also several minor seams of coal in the upper series; namely those of the Bathgate, Grangemouth, and Netherwood districts; and in the lower series, the Possil, Kilsyth, Kirkintilloch, Cowglen, Titwood, Hurlet, Campsie, Duntocher, Milngavie, Auchenheath, and Lesmahagow coals. These seams however are chiefly local, worked only in the immediate districts in which they are found.

The Bathgate seams are all of such an inferior quality that they are not even worked for the supply of the immediate district. The coal used in Bathgate is principally brought from the Monkland or from the Wishaw coalfield.

The Grangemouth coals are geologically the same as those at Redding, but are a little thicker and the seams are more numerous. In point of quality the coals are not equal to those of Redding and Slamannan. The collieries however have the advantage of being near the shipping port of Grangemouth, requiring little railway carriage, so that the inferior quality of the coals is compensated for by their cheapness, and the colliery proprietors are enabled to ship a considerable quantity of coal. The Netherwood coals are coking and smithy coals lying immediately under the Caulm limestone.

The Possil seams of coal lying in proximity to the ironstone seams are worked mainly for the supply of workmen's fires and engine fires at the collieries raising the ironstone. The Kilsyth coals are of a coking description, and are converted into coke at the collieries for the supply of Glasgow. The Kirkintilloch coals are generally steam coals.

The coals of Hurlet, Campsie, Duntocher, and Milngavie are inferior, and are used for steam purposes in those districts. The Lesmahagow and Auchenheath coal is used for the production of gas, and is the most valuable of Scotch cannels.

Detailed description of Ironstone Seams.—The Palacecraig Blackband ironstone is a seam of inferior quality, very poor and yielding only a small percentage of metallic iron. It has been worked only by the Gartsherrie Iron Company at Palacecraig near Airdrie. It extends over a large area in the Coatbridge district, but its quality has never been found such as to warrant its being much worked.

The Airdrie Blackband ironstone may be said to be almost wholly exhausted. It was upon this seam that the majority of the ironworks at Coatbridge were founded. It was discovered by the late Mr. David Mushet about the beginning of the century, and was highly valued for its freedom from deleterious impurities and for the quantity of carbonaceous matter which it contained.

The Soft Blackband ironstone resembles the Palacecraig ironstone in point of quality. It was worked near Airdrie, but was abandoned on account of its inferior quality.

The Cleland Roughband ironstone is peculiar to the mineral field around Cleland. It is a clayband yielding about 1000 calcined tons per acre.

The Bellside ironstone is found and worked in a limited area near Bellside, about 1½ mile south east of Newarthill. It is a blackband ironstone of good quality, and worth about 16*s.* per ton at the Coatbridge works. The most extensive working of this seam is at Greenhill in the parish of Shotts.

The Calderbraes ironstone is a band lying in the position of the Kiltongue coal, but not extending over a large area. It is worked at Faskine near Airdrie and at the Calderbank Iron Works. There is a thin gas coal in connection with the seam, which has recently been used for the production of paraffine oil.

The next seams are the Slaty bands of ironstone, which are the only seams lying in the upper series of minerals that are likely to yield a supply of blackband. The geological positions of these seams extend over an area equal to 30 or 40 square miles, a large part of which however is wholly unproved, while an equally large part has been proved to contain nothing beyond the mere position of the seams, the ironstones themselves being found to have thinned out. Both in thickness and quality these seams are exceedingly variable, measuring in some places as little as 4 inches thick, and in others as much as 3 or 4 feet. In its best state the quality of the ironstone is nearly equal to the Airdrie blackband; while at many places to the north of Airdrie it contains so large a proportion of sulphur as to render it quite unfit for ironmaking purposes. These bands of ironstone have been mostly worked at Bathgate, Crofthead, and Shotts. There are three slaty bands of ironstone as proved at Arden. The first of these is about 7 inches thick, and is supposed to be the same seam as that worked at Garbethill, Todsbughts, Cameron Glen, and Arden. The second or mid slaty band is about 15 inches in thickness, and is supposed to be the same ironstone as that found at Stepends, Crofthead, Armadale, and Shotts. The third band ranges in thickness from 7 inches to 4 feet, and lies in the same position as the seam at Goodockhill. In the neighbourhood of Bathgate the mid seam lies in connection with the famous Torbanehill coal, so highly valuable for the production of paraffine oil.

The next valuable seams of ironstone are those lying under the Possil or Cowglen limestone. The first of these are the Possil ironstones, two seams of excellent quality, the first of which is about 14 inches thick and the second about 10 inches, both lying in connection with thin beds of coal, which conduces much to economy in working them. These two seams of ironstone extend over a large district, and generally maintain a regular thickness. Under the lowest of them lies the Govan gas coal, occupying the same position as the Lesmahagow and Knightswood gas coal. The quality of this coal is best and it is worked most extensively at Lesmahagow.

The next seam is the California Clayband ironstone, of good quality, and worked at Kelvinside to the west of Glasgow.

The Upper ironstone of Garscadden is the next seam; it is a blackband of first-rate quality, varying from 8 to 14 inches in thickness.

The Lower ironstone of Garscadden is very much of the same quality as the preceding; it varies in thickness from 4 to 14 inches.

The Garibaldi Clayband ironstone underlies the last mentioned seam, averaging 14 inches thick.

The Dalry or Johnstone Blackband ironstone lies under the preceding seams, varying from 10 to 18 inches in thickness.

The ironstones worked at Comrie, Oakley, Inzievar, Cowdenbeath, and Lumphinnans in Fifeshire—Kinneil, Grange, and Balbardie in Linlithgowshire—Croy, Banton, Kilsyth, and Kirkintilloch in Dumbartonshire—Dolphingstone, Tranent, and Wallyford in East Lothian—Dryden in Mid Lothian—Johnstone and Paisley in Renfrewshire—Muirkirk and Dalry in Ayrshire—Possil, Garscadden, Kenmure, and Cadder in Lanarkshire—correspond in position with the ironstones lying under the Possil or Cowglen limestone.

Between the Dalry blackband ironstone and the Hurlet coal there are numerous clayband ironstones; but with the exception of one or two which have been partially worked at Hurlet there are none workable. In the position of the Hurlet coal itself there is sometimes found a band of ironstone, as at Easterhouse near Carnwath; but it is usually so contaminated with sulphur as to be quite unsuitable for ironmaking purposes.

Fitting and Working of Collieries.—The depth at which the seams of coal and ironstone are usually found varies from 20 to about

400 yards. The pits in the neighbourhood of Glasgow reach the Splint coal at from 140 to 180 yards, and at Baillieston it is reached at from 140 to 250 yards. At Wishaw the pits seldom exceed 120 or 140 yards to the Ell coal. The deepest pits sunk in the district are the Nitshill Victoria pit near Hurlet, sunk 350 yards to the Hurlet coal, about 5 miles south west from Glasgow; and the Snab pit at Kinneil, sunk 396 yards to the Eastermain coal. Some of the pits at Possil and the neighbourhood are sunk considerably more than 200 yards to the Possil ironstone.

The shape of the pits in plan is generally oblong, varying in size from 10 by 5 feet to 20 by 6 feet, according to the size of pumps to be put in the shafts. These shafts are usually divided into two compartments, a space of 4 or 5 feet at the rise end of the shaft being kept solely for the purpose of the upcast shaft, and the remaining distance divided for the pumping and winding arrangements. Fig. 3, Plate 74, is a plan showing the ordinary division of the shaft, the upcast shaft A at one end being 4 feet wide, and the pumping shaft B at the other end 5 feet wide, while the centre portion C, 9 feet wide, contains two sets of winding gear. The brattice or midwall is made of planks of red pine cut to the width of the pit, 9 inches deep and 3 inches thick, let into the wall on each side of the pit, and made air-tight by corner rackings of wood, cut out of timber about 6 inches square. The slides for the cages are of red pine, usually 5 inches square. The needles or buntings for securing the slides are usually cut to a section of about 9 inches by 3 inches, and are placed in the shaft about 9 feet apart.

There is not generally much water in the Scotch collieries. The usual size of the pumps varies from 8 inches to 16 inches diameter of the rising main; and when the latter size is not exceeded, the rods are usually worked by bell cranks driven by a horizontal engine with crank and flywheel. Of late years where the diameter of the pipes has exceeded 16 inches, direct-acting engines have been adopted, with the cylinder placed vertically over the pumping end of the pit. The usual length of the lifts or sets of pumps is from 90 to 100 yards.

Only two systems of working coal are employed in the district: that of "Stoop and Room," and the "Long Wall" working.

The Stoop and Room system, shown in Fig. 5, Plate 75, is much the same as that known in England as the "pillar and stall." As adopted in Scotland, it is customary to proceed with the working, leaving pillars or "stoops" D D containing about 55 or 60 per cent. of the coal for supporting the roof, until the pit has reached the limit of the area which has been laid out for working. The back working is then commenced, which consists in driving "rooms" through the stoops or pillars situated to the rise and on the level, as shown at E E, leaving only the four corners of the pillar. These corners are usually left 6 to 8 feet square, and are left in the pit permanently, and consequently are lost to the coal proprietor. The proportion of coal taken out of the field by this system varies from 70 to 85 per cent. of the total quantity of coal in the field. Seams of coal above 4 feet in thickness are usually worked by this method.

The Long Wall system is that usually adopted for working seams of coal under 4 feet in thickness and all seams of ironstone. This system is shown in Fig. 6, Plate 76, and by it the whole of the coal or ironstone is taken out of the pit. The working faces F F are carried forwards continuously from the shaft towards the rise and along the level on each side; and for the purpose of bringing away the coal as the working faces advance, packed roads G G are constructed through the goaf, by building up parallel walls of stone to support the roof, which are constantly carried forwards as the work advances.

The underground haulage is usually conducted by horses drawing on roads going along the level course of the seam. The rails employed are of cast iron, of an angle shape, about 4 inches deep in the side, cast in lengths of 4 feet, and weighing about 60 rails to the ton. The gauge to which they are laid is usually about 2 feet 10 inches, and each end of the rail is spiked to a larch sleeper, 6 inches broad by 2½ inches thick, costing 1½*d.* to 2½*d.* each. The haulage of coals from dip workings is accomplished by means of stationary engines placed underground, and supplied with steam from boilers at the surface. The steam is carried down the upcast end of the shaft in pipes, and the exhaust steam from the engine is conveyed about 20 feet up the shaft in pipes and then discharged to assist the ventilation. In some cases however the plan of letting the exhaust steam escape into the shaft has been found to injure the walls of the pit by loosening the strata; and in recent fittings it has been deemed advisable to convey the steam the whole distance up to the surface in pipes.

The dip and rise of the strata in the district varies from 1 in 10 to 1 in 3. When the inclination is so steep as 1 in 3, the minerals are lowered from the rise workings by self-acting inclines with a chain and a horizontal pulley at the head of the incline. The pulley is usually about 3 feet in diameter, and the chain for lowering the wagons is passed twice round the pulley to prevent slipping. The brake is applied to a friction ring cast on the side of the pulley.

The Scotch collieries cannot be said to be fiery: in few cases indeed are safety lamps required in working. Each pit has its fireman, who goes round the working faces of the pit each morning before the men proceed to work, to certify that all are free from fire. There are seldom any accumulations of gas except in places wholly shut off from the air current. In the "stoop and room" working, the stoops or pillars are almost invariably turned without the assistance of face brattices. The usual method of conducting the air current, as shown by the arrows in Figs. 5 and 6, is to split it at the pit bottom and lead it round the working faces, and back to the upcast end of the shaft by the heading drift H driven straight to the rise from the pit bottom. The size of the main airways is seldom larger than 20 square feet area, and the quantity of air travelling in each of the two splits does not often exceed 10,000 cubic feet per minute, or 20,000 cubic feet per minute total quantity of air passing through the entire mine.

The furnace is the universal rarefying power for ventilation. The steam jet as a principle has not been adopted, the only applications of steam for ventilating purposes being in working with underground engines, where the exhaust steam is discharged into the upcast shaft. The furnaces employed for ventilation are built a good deal after the Newcastle model; not so large certainly, but the same in shape. A section of a ventilating furnace is shown in Fig. 4, Plate 74; the firegrate K is about 7 feet long by 5 feet wide, placed about 20 inches or 2 feet above the floor. The spring of the arch is about 3 feet above the firebars, and the arch is turned with a rise of about 2½ feet in the centre. The furnace is usually placed about 40 feet back from the upcast shaft, and the arch over the fire is built forwards into the shaft. The whole volume of the return air from the workings is made to pass over the firegrate, as the return current is never inflammable, and there is never any necessity for dumb drifts.

The usual form of winding engines employed is a pair of coupled horizontal engines with cylinders varying from 20 inches to 30 inches diameter, 4 to 5 feet stroke, and 10 to 13 feet winding drums on the first motion. The weight of the hutch or wagon bringing the coal from the collier is about 4 cwts., and it contains about 10 cwts. of coal. Two hutches are usually raised at a time, so that the load on each rope is about 28 cwts., exclusive of the cage which weighs from 5 to 7 cwts. The quantity raised from each pit ranges from 50 to 350 tons per day. Hemp ropes are in most common use: where wire ropes are used, round wire ropes are becoming more common in deep pits. Flat wire ropes were a good deal used; but there is an impression among Scotch engineers that they are not economical, and this is attributed to an unequal straining on the different plies forming the rope, and they have been abandoned in many collieries on this account.

The cost of sinking and fitting the pits of course depends entirely upon the depth and the quantity of water to be contended with. The nature of the strata in all parts of the coalfield is about the same, consisting of alternating beds of sandstone and shale. Taking the average quantity of water to be raised from a pit at 250 gallons per minute, which is considered a fair quantity in the district, the cost of fitting and sinking a pit is—

for a pit 120 yards deep about £3,000.
„ 160 yards „ „ £5,000.
„ 200 yards „ „ £7,000.

These sums are exclusive of the cost of the working plant for properly working the colliery.

The cost of working the coal and putting it in wagons for delivery, including royalty and all charges, varies from 3*s.* to 4*s.* 6*d.* per ton of 22½ cwts. The first of these rates represents nearly the cost of raising the Wishaw Ell coal, and the latter the cost for the thinner seams under the Splint coal. The cost of raising and calcining the ironstone ready for delivery, including royalty and all charges, varies from 10*s.* to 18*s.* per ton of 22½ cwts. The general average cost of coal at the Coatbridge Iron Works, including lordship, cost of working, and railway charges, ranges from 5*s.* to 5*s.* 6*d.* per ton; and the cost of calcined ironstone from 13*s.* 6*d.* to 20*s.* per ton. Limestone is generally purchased from the limestone quarriers, and costs delivered at the works about 5*s.* 3*d.* per ton.

The average royalty paid to the landlord is about 8*d.* per ton on coal. The Wishaw Ell coal however has recently realised as much as 1*s.* 3*d.* per ton. The lordship on gas coal is one eighth of the hill price or the price at the pit mouth. On blackband ironstone the lordship is 2*s.* 6*d.* to 3*s.* 6*d.* per calcined ton of 22½ cwts.; and on clayband ironstone 1*s.* to 1*s.* 3*d.* per calcined ton of 22½ cwts. The lordship on limestone is about 4*d.* per ton.

Railway and Canal Accommodation.—The district is accommodated by the Caledonian, Edinburgh and Glasgow, Monkland, Scottish Central, and Glasgow and South Western Railways; and by the Monkland, Forth and Clyde, and Union Canals.

The Caledonian Railway lies over the most valuable part of the coalfield, and accommodates the most valuable coals in the upper series of minerals. On the line from Glasgow to Edinburgh it passes the Caulm limestone and fireclay field at Garnkirk. It enters upon the coalfield at Gartcosh station, running over the outcrop of the Kiltongue coal. It then passes the collieries of Gartsherrie, Coatbridge, Whifflet, Holytown, and enters upon the great Wishaw coalfield at Motherwell and leaves it near Carluke. The Lesmahagow branch brings the gas coal from Lesmahagow, the ironstone from Bankend, and the upper coals from Larkhall, Allanton, Ferniegair, and other collieries as far up the line as to near Auchenheath. The Wilsontown branch takes the gas coal and ironstone from Wilsontown and Forth. The Clydesdale Junction branch accommodates the Newton and Rutherglen coalfields, and serves as a route for the conveyance of coal from the Wishaw field to the south and east districts of Glasgow. The coal traffic on this line finds a shipping port at Glasgow, Greenock, Granton, and Leith on one system of railways; and at Kirkintilloch on board canal boats by means of the Kirkintilloch branch of the Monkland Railways.

The Edinburgh and Glasgow Railway main line passes over the Possil and Bishopbriggs ironstone field, and with the assistance of the Scottish Central and Monkland Railways opens up a communication between the Coatbridge ironworks and the Denny ironstone field. The Redding collieries are on the main line, and the Blackbraes collieries are connected with it by the Blackbraes branch. The Milngavie and Helensburgh branches pass over the Milngavie and Kelvinside mineral field. The only shipping port of the Edinburgh and Glasgow line on its own system is Grangemouth, but it is in communication with Leith and Granton by the Caledonian Railway.

The Monkland Railway system accommodates nearly the whole area containing the accessible portion of the slaty bands of ironstone, and conveys all the ironstones arising on it to the ironworks over one system of railway. It accommodates the Bathgate coal and ironstone field, and the coalfields of Slamannan and Airdrie. The shipping ports on the canal are Causeway End and Kirkintilloch, and Boness on the sea board.

The ironstone fields of Govan, Paisley, and Johnstone are accommodated by the main line of the Glasgow and South Western Railway.

The Monkland Canal conveys the coals in the Baillieston and Drumpeller districts to the ironworks or to Glasgow, or to Greenock by the Forth and Clyde Canal. The Union Canal conveys the coals from Redding and Causeway End to Edinburgh.

In conclusion it may be stated generally that the area containing the most valuable coals, which are those above and including the Splint coal seam, is comprised within the area shaded dark on the general plan, Fig. 1, Plate 72: it is bounded on the west by Glasgow; on the north by Greenfield, Cardowan, Easterhouse, Heatheryknowe, Gartsherrie, Airdrie, and Standrig; on the east by Clarkston, Chapelhall, and Cleland; and on the south by Dalserf and Larkhall. The area containing the Virtue Well, Kiltongue, and Drumgray coals, and the ironstones in their locality, extends as far north as Jawcraig, Falkirk, and Grangemouth; east as far as Bathgate; and south to near Carluke. The area containing the seams in the locality of the Possil, Garscadden, and Dalry ironstones extends as far north as Duntocher, Milngavie, Kilsyth, and Denny; and as far east as Bathgate and Wilsontown; and nearly as far south as Lanark. It has been from these districts that the supply of coal and ironstone has been almost wholly derived during the last hundred years.

The whole Glasgow mineral district, forming the subject of the present paper, contains 111 blast furnaces producing about 900,000 tons of pig iron per annum, and consuming about

2,500,000 tons of coal
1,485,000 tons of ironstone
445,000 tons of limestone.

The entire district contains about 260 collieries, which raise annually about 8,500,000 tons of coal, or nearly 77 per cent. of the whole produce of Scotland.

Mr. **Neil Robson** thought the paper just read gave a clear account of the present state of the Glasgow coalfield, and he could confirm the accuracy of the statements contained in the paper. He enquired whether any attempts had been made to introduce coal-cutting machines practically in any part of this district, as he thought an application of machinery for that purpose was now greatly needed for enabling the coal masters to keep their men in order. He had seen a coal-cutting machine at work at Hetton Colliery, Durham, about a year ago, which he thought highly of as a step in the right direction, though it would require a great deal to be done to it in order to make it practically useful. That machine had been obtained from Leeds by Mr. Nicholas Wood, for the purpose of showing it in operation at the Hetton Colliery during the meeting of the British Association at Newcastle. It was driven by compressed air, which was conveyed down the pit and then carried to the working face of the coal at a distance of 500 yards from the bottom of the shaft. He believed these machines were already increasing in number, but he was not aware of any of them having been put to work yet in the neighbourhood of Glasgow.

Mr. W. **Moore** believed the only trial yet made in Scotland of a coal-cutting machine had been at a colliery at Redding, near Falkirk. The machine was worked by compressed air, conveyed down the pit in pipes of 3 or 4 inches diameter, and led a quarter of a mile underground to the machine.

Mr. **Ralph Moore** said he had witnessed the experiments with two different coal-cutting machines at the West Ardsley Colliery near Wakefield and at Redding Colliery near Falkirk, but in neither case did the results lead him to think that the machine would become practicable for some time to come. The West Ardsley machine was simply an ordinary pick worked through a bell-crank lever by the piston rod of the air cylinder, giving a motion corresponding to the ordinary horizontal stroke of the pick in hand work: this did not seem to work very well at present, though it appeared likely to be made to answer ultimately. The trial at Redding had been made with a rotary motion of two picks, something like a circular saw with only two teeth, which had appeared to be a better plan: as yet however the machine had not been found fully successful, and it had consequently been abandoned at Redding for the present.

Mr. E. A. **Cowper** said that the coal-cutting machine working at the West Ardsley Colliery was that of Messrs. Donisthorpe Firth and Ridley of Leeds, and was working regularly at that colliery.

The action was simply that of an ordinary pick, worked backwards and forwards by means of a bell-crank lever, producing the same stroke that a man would give by hand, but with the advantage of greater force and regularity in the blows of the machine. The pressure of the compressed air was 40 lbs. per square inch, and the machine was worked by a boy moving the slide valve of the air cylinder by a handle for each stroke of the pick, in the same manner as in working a steam hammer. From the accounts that he had heard of the machine it appeared to be a thoroughly practical one, and performed the work of undercutting the coal, which was ordinarily done by the colliers lying on their backs. Mr. Nicholas Wood had expressed a very favourable opinion of the machine, stating that in hard coal it undercut about 50 feet length in the course of a night, and in softer coal about 100 feet; and the coal so undercut was then got by the colliers in the day.

The President enquired what length of coal a collier could ordinarily undercut in an hour, and what was the size of the excavation made in undercutting to a depth of 3 feet in from the face.

Mr. Ralph Moore replied that a collier could undercut about 2 feet length of coal in an hour, and in undercutting to a depth of 3 feet the width of the cut would be about 6 inches at the face, tapering to a point at the further end. The motion of the pick in the West Ardsley coal-cutting machine was not exactly like that given by the collier by hand, as the machine merely struck the blow with the pick by a reciprocating movement, but a collier after striking the blow used the pick as a wrench to break the coal away; and until that wrenching motion also was obtained in working the pick by the machine, he did not think it would succeed very well. The circular saw motion that had been tried at Redding had been attempted as an improvement upon the simple pick, and the machine at Redding undercut a length of about 3 or 4 yards per hour to a depth of 3 feet in. That was the greatest amount of work it had accomplished in the hard coal at Redding; but the machine at West Ardsley had done considerably more, because it was working in very much softer coal.

Mr. **Neil Robson** remarked that the machine which he had seen at work at the Hetton Colliery gave a great saving in coal as well as in collier's labour; since instead of taking out a cut 6 or 9 inches wide, as in hand cutting, it made a cut only about 2½ inches wide on an average, and thus saved the rest of the coal that would have been excavated in hand labour, as the coal cut out was all made into dross or slack by the process of cutting. This did not matter so much in the case of the Newcastle coal, as that was a caking coal, and therefore the small coal was valuable and could be used for making coke; but with other coals the small coal was not of so much use, and was in fact partly wasted. The saving effected by the machine in cutting the coal was therefore great in respect of coal as well as in labour. He accordingly hoped to see coal-cutting machines brought into more general use.

Mr. J. **Manning** had seen a hydraulic coal-cutting machine at work at the Kippax Colliery near Leeds, constructed by Messrs. Carrett and Marshall, having a horizontal arm projecting from the piston rod at the side of the machine and carrying a cutting tool or chisel, which was worked by water pressure with an action like a horizontal slotting machine; so that as the machine travelled along the face of the coal, the tool cut out a narrow notch or slot to the required depth. It thus saved the large amount of waste that was occasioned by the quantity of small coal necessarily made in undercutting by hand labour.

Mr. W. P. **Beale** enquired whether there was found to be any danger of spontaneous ignition of the coal in the Scotch collieries in working on the long wall system, where it was necessary to keep roads open through the goaf; and what precautions were adopted to guard against such an occurrence. He asked also whether any case was known in which ignition had been the result of the exposure of pyrites to the air in the pit, or whether there was any other cause of danger.

Mr. W. **Moore** believed the only coal in Scotland liable to spontaneous ignition was the Hurlet coal, the lowest in the coalfield. It took fire a few years ago in the Victoria Pit West, near Nitshill, but the fire was very slight, and was soon put out.

In that case the ignition was attributed to pyrites, nor did he know of any other cause. Spontaneous ignition however was not by any means of frequent occurrence, and that was the only instance of it that he knew of during the past seven or eight years.

Mr. **Ralph Moore** said that in collieries where there was any liability to spontaneous ignition of the coal, in working on the long wall system, the practice was to build a double wall on each side of the roads through the goaf, the centre of each wall being filled in like a cofferdam with about 6 or 8 inches thickness of sand. Then when the roof came down it compressed the sand and made the walls perfectly air-tight, preventing any air from getting through into the goaf. He had had occasion recently to examine some workings where the roads had been constructed in that way through the goaf, and at one place he had had a hole broken into the wall at a distance of about 30 yards behind the point to which the workings of the coal had then advanced, in order to see the state of the wall after standing that length of time; and he found the layer of sand inside the wall was quite solid, forming an effectual barrier to the passage of air.

The **President** enquired what was the relative durability of the hemp and wire ropes used for winding in the pits, and whether any steel wire ropes were used for the purpose in the Scotch collieries; also what diameter of pulley was generally used for them to work over.

Mr. W. **Moore** had found that a hemp rope used for winding in a pit 200 yards deep lasted about 15 months with ordinary working, drawing from 150 to 200 tons per day; and a round iron wire rope under the same work lasted 12 or 13 months, while a flat wire rope lasted only about 11 months. The pulleys employed over which the rope passed were generally 10 to 12 feet diameter. He did not know of any steel wire ropes being used at any of the collieries in that district.

Mr. D. **Adamson** believed steel wire ropes were now being adopted for winding at several collieries in England, and had no doubt their application for that purpose would be very valuable, as he understood the practical success of steam ploughing had been attributed by Mr. Fowler in a great measure to the introduction of steel wire ropes in place of iron wire, on account of the superior strength and lightness of the steel ropes. The results of working with steel wire ropes as compared with hemp ropes for colliery winding had been found to be that, when a flat wire rope passed over the winding drum and the pulley with both bends in the same direction, the steel rope lasted longer than the hemp rope of the same original tensile strength; but in winding with two ropes, the second rope must pass over the pulley and under the winding drum, and was thus bent in opposite directions; and in that case a steel rope was found not to last half as long as when both the bends were in the same direction.

The PRESIDENT moved a vote of thanks to Mr. Moore for his paper, which was passed.

The following paper, communicated through Mr. Daniel Adamson of Manchester, was then read:—

ON THE CONSTRUCTION OF BLAST FURNACES AND THE MANUFACTURE OF PIG IRON IN THE CLEVELAND DISTRICT.

By Mr. JAMES GEORGE BECKTON, of Whitby.

Within the last ten years the Blast Furnaces which have been erected in the Cleveland district have been gradually increased in size both in diameter and height; and these alterations have thus far been attended with good results, so much so that almost all the new furnaces now in course of erection are being built with boshes ranging from 16 feet to 22½ feet diameter, and from 60 feet to 75 feet in height from the bottom of the hearth to the filling plates at the top. Previously the furnaces ranged from 13 feet to 15 feet diameter at the boshes and from 45 feet to 50 feet in height, the extreme increase being about 70 per cent. in both dimensions. The maximum diameter of the boshes appears not yet to have been attained; and the limit to the height will apparently be found in the strength of the coke to support the crushing force of the high column of materials in the large blast furnace. The make of pig iron has increased at the same time from 200 tons per week in the small furnaces to 300 tons in the large furnaces.

The average quantity of materials used in the production of one ton of pig iron in the large furnaces is as follows:—

26	cwts. of Durham coke,
70	cwts. of Cleveland ironstone,
15	cwts. of limestone,
10	cwts. of coal for boilers, hot-blast stoves, and calcining kilns.
121	cwts. total

or about 6 tons of materials per ton of iron made. Formerly the quantity of coke used per ton of iron made averaged 35 cwts. instead of 26 cwts., and the quantity of coal 20 cwts. instead of 10 cwts. The writer does not attribute the whole of the saving of fuel which has taken place to the increased size of the furnaces alone, as there are several other improvements which have combined to produce an economy of fuel in the manufacture of pig iron in the Cleveland district, of which the following are some of the principal:—

First, the more efficient management which has taken place at the different works.

Second, the better adaptation of engine power and hot-blast stoves to the requirements of the furnaces.

Third, the improved system of calcining the ore, which was formerly carried on by clamping in the open air, but is now performed in properly constructed calcining kilns.

Fourth, the higher degree of temperature of the blast supplied to the furnaces, which was formerly heated in the hot-blast stoves to only 600° or 700° Fahr., but is now very generally being supplied to the furnaces at a temperature of from 800° to 900°.

Fifth, the plan of taking off the waste gas from the furnaces and burning it at the boilers and hot-blast stoves, in place of using additional coal for this purpose.

The application of the waste gas to the boilers and hot-blast stoves is becoming very general at the different works in the district; and arrangements are now being made at several of the new works in course of erection for applying it to the calcining kilns, for the purpose of calcining the ironstone. The plan in general use for taking off the gas from the blast furnace is the closed furnace top with bell and hopper sufficiently large to charge from 8 to 10 tons of materials into the furnace at once, and with an arrangement for raising and lowering the bell by hand. The impression seems to be gaining ground that taking off the gas with the closed top, and in connection with a large chimney double the height of the furnaces, does not interfere with the operations of the large furnace, either as regards economy of fuel or quality and make of iron.

A noticeable feature in the large furnaces is the greater amount of time the materials are allowed to remain in the furnace. The capacity of the Thornaby furnaces, shown in section in Fig. 4, Plate 80, with 20 feet boshes and 60 feet height, is 12,361 cubic feet; the area of the boshes is 314 square feet, and the make of iron 300 tons weekly per furnace. The capacity of the small furnaces which were formerly erected, with 14 feet boshes and 50 feet height, is 5553 cubic feet; the area of the boshes is 154 square feet, and the make of iron 200 tons weekly per furnace. In the large furnace therefore there are more than twice the quantity of materials undergoing the process of heating, and also remaining a longer time in the furnace. Moreover the area of the boshes in the large furnace being double that in the small furnace, while the quantity of iron produced by the large furnace and consequently the quantity of blast supplied is only one and a half times as much as in the small furnace, it follows that the ascending gases pass through the materials at a slower velocity and at a lower temperature in the large furnace. This allows the coke to descend to the zone of fusion without losing so much of its carbon in the formation of carbonic oxide as previously in the small furnace; and hence arises the greater economy of fuel in the large furnace. To produce 300 tons of pig iron per week, the large furnace requires to be supplied with 8000 cubic feet of blast per minute at a pressure of 3 lbs. per square inch.

Fig. 1, Plate 77, is a vertical section of one of four furnaces at the Ormesby Iron Works, Middlesbrough, belonging to Messrs. Cochrane. These furnaces were erected in 1855, and were the largest in the district at that time; the boshes are 16 feet diameter and the height is 56½ feet. The furnaces are constructed upon land consisting of mud and silt, and piling had therefore to be resorted to in order to secure a good foundation for the furnaces. A bed of concrete was placed on the top of the piles, and six inverted arches were turned on the top of the concrete, and the brick pillars carried up, and strong cast iron bearers fixed across the top for carrying and binding the brickwork of the barrel and boshes. The outer shell is bound with wrought iron hoops, fixed near enough together to prevent the barrel from cracking. The boshes are at an angle of 75° from the horizontal.

Fig. 2, Plate 78, is a vertical section of one of four furnaces erected in 1858 at the Jarrow Iron Works, Newcastle-on-Tyne. There was a good strong clay for the foundations of the furnaces to rest upon; the brickwork was carried up to the floor line, then twelve cast iron columns were erected, and wrought iron casings fixed on the top of these. The casings extend from the top of the five tuyere houses to the top of the boshes, above which the barrel is bound with wrought iron hoops supported by T irons, the latter being carried up to the top, and a flat ring rivetted to them sufficiently strong to carry the floor plates. The boshes are 18 feet diameter, at an angle of 66° from the horizontal, and the furnaces are 60 feet high.

Fig. 3, Plate 79, is a vertical section of one of three furnaces at the Normanby Iron Works, Middlesbrough, belonging to Messrs. Jones, Dunning and Co. These furnaces were erected in 1860, and are constructed upon a bed of concrete, on clay of a weak nature; they are supported on brick pillars and hooped similarly to the Ormesby furnaces. The boshes are 18 feet diameter, at an angle of 72° from the horizontal, and the furnaces are 58 feet high.

Fig. 4, Plate 80, is a vertical section of one of three furnaces erected in 1862 at the Thornaby Iron Works, South Stockton-on-Tees, belonging to Messrs. Whitwell. These furnaces are constructed upon piles, in consequence of the land being mud and silt; they stand each upon twelve cast iron columns, and are cased with iron similarly to the Jarrow furnaces. The boshes are 20 feet diameter, at an angle of 68° from the horizontal, and the furnaces are 60 feet high.

Fig. 5, Plate 81, is a vertical section of one of three furnaces which are being erected at the Acklam Iron Works, Middlesbrough, by Messrs. Stevenson, Wilson, Jaques and Co. They are being built on piles, in consequence of the land being mud and silt, and are each supported by twelve cast iron pillars. The brickwork around the boshes is cased with plates, and from the boshes up to the top the barrel is bound with hoops and T irons. The boshes are 22½ feet diameter, at an angle of 68° from the horizontal, and the furnaces are 70 feet high. These furnaces the writer believes to be the largest in dimensions that have ever been erected, and their contents will amount to no less than 1250 tons of materials per furnace: they are expected to produce each 350 tons of pig iron per week.

Mr. D. ADAMSON regretted that Mr. Beckton was unexpectedly prevented from being present at the meeting. With some of the blast furnaces in the Cleveland district he had himself had an opportunity of becoming acquainted; and in reference to the semiclosed plan of furnace top, for taking off a portion of the gas from the furnace throat, as shown in the drawing of the Thornaby furnace, Fig. 4, the construction of top in this case was similar to that in use at Messrs. Schneider's furnaces near Ulverstone; but although at the Ulverstone furnaces it had been found to work so successfully that the same plan was being adopted for more furnaces at the same works, in the particular instance of the Thornaby furnaces it had not been found to answer. The centre tube or brick chimney for taking off the gas was carried upon six arches springing from the inside of the furnace throat, and the charging of the materials into the furnace was done through the spaces left between the arches; and the reason of the failure of the plan at the Thornaby furnaces was that constant trouble was occasioned by the damage done to these arches in charging, owing to the large size of the material in the charges. The Cleveland ironstone was raised from the mines and supplied to the furnaces in very large pieces, and would not pay for being broken to a smaller size, on account of its friable nature and the quantity of waste that would be made in breaking it up; and in charging the furnace with these large pieces they broke down the arches carrying the centre tube, so that this plan had now been abandoned at the Thornaby furnaces, and they were about to have closed tops put on of the usual construction for taking off the whole of the gas.

Independent however of the trouble arising with the arches in the semiclosed plan of furnace top, it was also found at the Thornaby furnaces that the portion of the gas so taken off was not sufficient in quantity for the purposes of raising steam at the works and heating the blast, even without attempting to use any of the gas for calcining the ironstone. In the discussion of this subject at the Liverpool meeting in last year he had urged the desirability of taking off the whole of the gas from a furnace, on account of the large additional heating power then at command; and this view appeared to be confirmed by the experience in the present instance at Thornaby, and by the statement given in the paper just read that at some of the Cleveland furnaces where the top was entirely closed the gas was likely to be employed for calcining the ironstone in addition to heating the steam boilers and the hot-blast stoves.

The PRESIDENT enquired what was the effect of the increased size of the Cleveland blast furnaces upon the quality of the iron made.

Mr. D. ADAMSON understood that in the larger furnaces foundry iron was made with rather less trouble than in the smaller ones; and with considerably less fuel, according to the statement in the paper. The charge was thus lighter and the iron was made at less cost in the larger furnaces, which was attributed in the paper to the greater length of time that the materials remained in the larger furnaces.

The PRESIDENT asked what size of blowing engine was used for the large furnace at the Acklam Iron Works.

Mr. D. ADAMSON was not aware what size of engine was used at the Acklam furnaces, but the majority of the Cleveland furnaces were supplied with blast by a number of small blowing engines, and the rest by a single large engine. With regard to the pressure of the blast, he believed 3 lbs. per square inch or rather less was usually about the pressure at the engine in the Cleveland district, but he doubted whether the full pressure of the blast was always obtained in the furnaces, as it had been found by applying gauges on the tuyeres at the Thornaby furnaces that the pressure at that point was considerably below what it was at the engine. At the Norton furnaces of Messrs. Warners, near Stockton-on-Tees, the pressure originally employed of 2¾ lbs. per square inch had now been reduced to only ½ lb. per square inch; and he understood the lighter blast was preferred at those furnaces, and that a greater quantity of foundry iron was made than with a heavier pressure of blast.

The **President** enquired what was the usual number of tuyeres in the Cleveland furnaces.

Mr. D. **Adamson** replied that from three to six tuyeres were usually employed. At the Norton furnaces three large tuyeres were now used with the light blast, instead of six smaller tuyeres employed previously with the heavier blast; and from the reduction in the pressure of the blast, much less engine power was now required in blowing the furnaces for the same make of iron. At another furnace however in the neighbourhood, the engines had been kept loaded to 2¾ lbs. per square inch pressure, while the pressure of the blast was reduced by throttling its passage through the main by means of a stop valve; and in that instance consequently the full benefit of saving in engine power by working with a lighter blast had not been realised.

Mr. G. **Thomson** observed that the size of the blast furnace was a very important subject to iron makers, and one upon which experience differed a good deal; and it was therefore highly desirable to get all the information possible, in order to make a fair comparison between different sizes of furnace. One point to be enquired into was the relative quantity of iron produced and of blast supplied in the large and small furnaces: in the large furnaces, 60 feet high and 20 feet diameter of boshes, making 300 tons of iron per week, the quantity of blast had been stated in the paper to be 8000 cubic feet per minute; and he enquired what was the quantity of blast supplied to the smaller furnaces, 50 feet high and 14 feet diameter of boshes, making 200 tons of iron per week.

Mr. Neil **Robson** did not know the quantity of blast supplied in the smaller Cleveland furnaces, but in the blast furnaces of the Glasgow district the quantity of blast supplied to a furnace about 50 feet high and 16 feet diameter of boshes was usually supposed to be about 6000 cubic feet per minute.

Mr. C. Cochrane thought the 8000 cubic feet of blast per minute, which had been stated to be the supply to the large Cleveland furnaces, must be the theoretical quantity measured by the total displacement at the blast engine, without any allowance being made for escape between the piston and the cylinder and for leakages in the blast main: for the quantity of coke consumed in the furnace, 26 cwts. per ton of iron made, would not require he thought more than 6000 to 6300 cubic feet of blast per minute, and he could not understand therefore so much as 8000 cubic feet per minute being supplied to the furnace.

Mr. G. Thomson remarked that 6000 cubic feet of blast per minute would be a maximum quantity in Staffordshire, and there were many furnaces of smaller size in that district to which a much smaller quantity of blast was supplied.

Another point upon which further information was required in connection with the Cleveland blast furnaces was the temperature of the blast in the large and small furnaces, and whether the large furnaces had been worked with the lower temperature of blast used in the smaller ones. It appeared from the paper that the blast for the larger furnaces was heated to 800° Fahr., while in the smaller furnaces the temperature had not been carried beyond 600°; and in order that a fair comparison might be arrived at between the different sizes of furnace, he should be glad to know the result of working the larger furnaces at the lower temperature of 600°, the same as the small furnaces, since the conditions of working should be made as nearly as possible the same in the different furnaces. The actual temperature of the blast he believed was generally much higher than was indicated by the ordinary rough test of holding a strip of lead in the blast to be melted by the heat; since in order to melt the lead at all under such circumstances, the temperature of the blast must be considerably above the melting point of the metal, and the real temperature was therefore not ascertained with any approach to accuracy by the plan of melting metals in the blast. He enquired how the heat of the blast was ascertained when it was much above the melting point of lead, and whether any pyrometer was employed for showing the temperature accurately.

Mr. C. **Cochrane** replied that for temperatures above that indicated by the melting of lead in the blast a strip of zinc was used as the test instead of lead, and by that means a temperature as high as about 850° was indicated, the melting point of zinc being 770° Fahr.; for the actual temperature of the blast, when hot enough to melt either lead or zinc, was found to be as much as 80° or 90° above the melting point of the metal. This was ascertained to be the case as a general rule, whatever the melting point of the metal employed, as was shown by the aid of the improved pyrometer constructed on the principle of measuring the temperature of a copper ball heated in the blast, by immersing it in a vessel of water; which afforded the means of measuring with the greatest accuracy the highest temperatures that were likely to be met with in practice.

Mr. E. A. **Cowper** explained that the pyrometer referred to was an improved arrangement of that invented by Mr. John Wilson and described at a former meeting of the Institution (see Proceedings Inst. M. E., 1852, page 53), and was a very simple and accurate contrivance for measuring high temperatures. It consisted of a copper vessel holding exactly a pint of water, and a small cylindrical piece of copper made of such a size that its total capacity for heat should be 1-50th that of the pint of water; this copper piece was held for a sufficient time in the current of heated blast until it had acquired the full temperature of the blast, and it was then dropped into the vessel of water, when each 50° that the temperature of the copper had been raised produced a rise of 1° in the temperature of the water; and thus the real temperature was at once read off from a thermometer inserted into the water, having a properly divided scale showing 50° for each 1° of the ordinary scale (see Proceedings Inst. M. E., 1860, page 59). It was by this means that it had been ascertained that, when the heat of the blast was tested by a stick of metal being just melted on exposure to the current, the actual heat of the blast was about 70° to 90° Fahr. above the melting point of the metal. Thus if lead, melting at 620°, were just melted by the blast, the heat of the blast might be taken to be about 690°; zinc melted at 770° and would show about

840° ; and antimony did not melt at less than 830°, and its melting would therefore indicate about 900°. Of course if the stick of metal were melted quickly in the blast, it showed that the temperature was much higher than the melting point of the metal; and ordinarily the sticks of antimony of about 5-16ths inch diameter became fused in 3 or 4 seconds by exposure to the heated blast from the regenerative hot-blast stoves.

Mr. **Neil Robson** observed there could be no doubt as to the importance of the question of the height of blast furnaces; and it appeared from the paper a height of 70 feet had now been reached in the Cleveland district, while in the neighbourhood of Glasgow the highest furnace was only 55 feet, and generally the furnaces were not more than 42 feet high. At the Ardeer Iron Works in Ayrshire, where there were four furnaces, each 52 feet high and 16 feet diameter at the boshes, the regular make of iron was 1000 tons per week, or an average of 250 tons per week from each furnace: occasionally one or two of the furnaces would make 270 tons per week, while the others might make less than 250 tons at the same time; but 1000 tons per week was the regular average make throughout the year taking all four together. The highest make in the Cleveland district was stated at about 300 tons per week, with 60 feet height and 20 feet diameter of boshes; but in comparison with the Scotch furnaces the make of the larger Cleveland furnaces ought to be as much as 400 tons per week for the size of furnace used. The temperature of blast employed was in both cases from 800° to 900°, and the pressure about 3 lbs. per square inch. Hence he thought the cause of the smaller produce of the large Cleveland furnaces was to be sought in the materials that had to be worked, the nature of the ironstone to be smelted and the quality of the fuel to be used. In the Ardeer furnaces the ore employed was in a great measure the blackband ironstone, and the fuel was raw coal; and he presumed these must be easier smelted than the materials in the Cleveland district, since the Scotch furnaces, though so much smaller, produced nearly as much iron in the same time.

The **President** enquired whether the furnaces 55 feet high and 16 feet diameter at the boshes were the largest furnaces in the Glasgow district.

Mr. **Neil Robson** replied that those were the largest of the Scotch furnaces. The increase of height now taking place in the Cleveland district he considered was a step altogether in the right direction, and he thought the proper height of furnace had probably not yet been attained in Scotland.

Mr. **F. J. Bramwell** enquired what was the amount of the different materials employed in the Scotch furnaces of 52 feet height and 16 feet diameter, to produce a ton of iron; because the production of a furnace must of course depend upon the total quantity of the materials that had to pass through it for each ton of iron made. It appeared from the paper that in the Cleveland district about 5½ tons of material went into the furnace per ton of iron made; and as the Scotch blackband ironstone calcined was a far richer material than the Cleveland ironstone calcined, it would be expected that less material would be found to be required per ton of iron in the Scotch furnaces than in the Cleveland furnaces, and thus the production of the latter would be less in proportion to their capacity than that of the Scotch furnaces.

Mr. **Neil Robson** considered the quantity of materials required in the furnace per ton of iron made must certainly depend upon the nature of the ironstone used; and in the Scotch furnaces that he had referred to the ironstone employed was about two thirds blackband and one third clayband and hæmatite ore. With these ironstones the quantities of materials required to make a ton of pig iron were about 38 cwts. of ironstone, 36 cwts. of raw coal, 6 cwts. of limestone, and 10 cwts. of coal for the boilers, hot-blast stoves, and calcining: making a total of 4 tons 10 cwts. of materials required per ton of iron made, or about 4 tons passing through the blast furnace to yield 1 ton of iron, as compared with the 5½ tons stated to be required in the Cleveland district to produce the same quantity.

Mr. **D. Adamson** observed that the difference was still more marked in the case of furnaces working with the hæmatite ironstone, where the quantity of ironstone required per ton of iron made was about 35 cwts., with 5 cwts. of limestone and 20 cwts. of coke, making a total of only about 60 cwts. or 3 tons of materials passing through the furnace to make a ton of iron. At Messrs. Schneider's furnaces at Ulverstone, in consequence of this advantage in working the hæmatite ore, he understood the regular make of each furnace was not less than 400 tons of pig iron per week, which could be increased to 600 tons per week by heavy working; and in one instance, by way of trying what could be done, a production of as much as 700 tons in a week had been obtained from one furnace. A mere glance at the works was sufficient to show the great difference in the ores worked in the two districts, by the comparative absence of slag at the furnaces working the hæmatite ore, and the very large quantity of slag produced from the Cleveland furnaces, which indicated the larger quantity of material that had to be operated upon in the latter case to produce a ton of pig iron. In one district the process was comparatively cleanly, while in the other it was dirty and rough, leaving a great deal of refuse.

Mr. F. J. **Bramwell** enquired what was the length of time that the charge took to pass through the furnaces of the different sizes described in the paper.

Mr. C. **Cochrane** said that in the Ormesby furnaces of 56½ feet height and 16 feet diameter, 36 hours was reckoned as the time that the charge remained in the furnace; that is from the time the material was put into the furnace till it was converted into iron in the hearth 36 hours was all that was necessary. This was ascertained by observing that when any alteration was made in the charging of the materials at the furnace top, it took about 36 hours before the corresponding change took place in the iron produced in the hearth. The time the material remained in different sizes of furnaces was in direct proportion to the capacity of the furnace or the quantity of material contained in it, provided the volume of the blast supplied to the furnace remained the same.

Mr. F. J. **Bramwell** observed that if that were the case, the length of time that the materials remained in the large furnaces would probably be as much as three days; and he enquired whether it was likely they were actually so long in passing through the furnace.

Mr. C. **Cochrane** explained that, if the volume of blast supplied to the larger furnaces were no more than what was blown into the smaller furnaces in which the materials remained about 36 hours, the time in the larger furnaces of 70 feet height and 22½ feet diameter would no doubt be as much as 72 hours, owing to the capacity of the furnace and quantity of material being double as large. The length of time however was not a question solely of the quantity of materials in the furnace, but also of the volume of blast supplied; and the larger furnace would stand a very much heavier volume of blast without working less economically. In practice the increased quantity of blast supplied to the larger furnace was probably such as to reduce the time of the material being in the furnace to about 40 hours; but he was not aware what was actually the state of the case in that respect. He did not think there was any advantage to be gained by unnecessarily detaining the materials in the furnace; and as 36 hours was found sufficient for their passage through the smaller furnaces in the Cleveland district, there appeared no object in endeavouring to make them take longer in passing through the larger furnaces.

Mr. G. Thomson thought it was still a question for consideration whether the proper length of time for keeping the materials in the blast furnace had yet been arrived at, and whether this ought to be longer in the larger furnaces than in smaller ones. Of course if the time was to be the same in both, the larger furnaces would require a very much increased volume of blast, so as to make the larger quantity of materials pass through with sufficient rapidity. The actual length of time that the materials took to pass through the large furnace might be deduced, he thought, from the capacity of the furnace and its weekly make, if the time of 36 hours in the smaller furnace were adopted as a criterion. For if 36 hours were the time in a furnace of 5000 cubic feet capacity, producing 200 tons of iron per week, it would follow that in a furnace of 12000 cubic feet capacity, working with the same materials and producing 300 tons of iron per week, the materials would occupy $36 \times \frac{12000}{5000} \times \frac{200}{300}$ or about 57 hours in passing through the furnace. The length of time must however depend upon the nature of the materials employed in different districts, which would determine the volume of blast that could be supplied to the furnace.

It was not the size of a furnace alone however that affected its make, but the shape of the furnace had also much to do with the result; and the shapes shown in the sections of the three furnaces at Ormesby, Jarrow, and Normanby were so different, that it would be highly desirable to ascertain what were the differences in the results of working of these furnaces with the same materials.

The **President** enquired what had been the reasons why the plan of taking off the waste gas from the blast furnace had not been carried out at the Scotch furnaces, as he was not aware of the gas being taken off from any furnaces in Scotland, though so much had been done in that respect in other places.

Mr. **Neil Robson** replied that taking off the waste gas from the furnace head, and applying it to heat the boilers and hot-blast stoves and to calcine the ironstone, had never been successfully accomplished hitherto in any of the Scotch ironworks: it had been tried ten or twelve years ago at several ironworks in Lanarkshire, but there had been several bad explosions of the gas which had done great damage, and these, combined with the belief that the closed top had a prejudicial effect on the working of the furnace, led to the abandonment of the attempt. He did not see however why it should not yet prove successful, and was glad to learn it was now succeeding in the Middlesbrough district. Perhaps some explanation of the failure in the Scotch furnaces might be found in the use of raw coal in those furnaces, which produced more gas than the coke burnt in the Cleveland furnaces.

Mr. C. **Cochrane** thought the explosions that had occurred in taking off the waste gas could only have arisen from a want of proper precautions. At the Ormesby furnaces they had had one or two severe explosions in starting the process, from the men not being quite up to it, and allowing the air to get back into the gas main, and not igniting the gas at the proper time. The danger was that, if the gas was not ignited at the point intended, it accumulated in the chamber where it ought to be burning; and a light applied then was necessarily followed by instant explosion. It was only necessary however to keep the gas constantly ignited at the proper point, and to take care that the unignited gas was never allowed to reach a chamber where it could become mixed with air and afterwards be ignited. The use of raw coal in the blast furnace instead of coke would not at all increase the danger of explosion; the only difference would be that a richer and more valuable gas would be given off from the furnace burning coal, and when taken off such a gas would develop a greater amount of heat for the purposes to which it was applied.

The PRESIDENT remarked that there was all the more reason on that account why the waste gas should be utilised from the Scotch blast furnaces, and it was satisfactory to learn that there were no practical obstacles to the plan which might not be successfully overcome. He enquired whether there was any mechanical means of preventing the air from ever passing back into the unignited gas, or whether it depended upon the care of the workmen in keeping the gas constantly ignited.

Mr. C. COCHRANE replied that it was necessary to keep a small fire always burning in any chamber where the gas was to be lighted, in order to ensure maintaining such a temperature that the gas should always become ignited at the moment of entering the chamber.

Mr. G. ADDENBROOKE thought the reason why the waste gas had not been more extensively taken off from blast furnaces was the want of a sufficiently powerful chimney draught to draw off the gas when the furnace top was left partly open. With an entirely closed top there was indeed the pressure of the blast in the furnace, to follow up the gas and aid in expelling it from the top of the furnace; but many descriptions of coal were not fitted to stand the increased pressure of blast that was rendered necessary to a certain extent with a closed top in order to overcome the consequent back pressure in the furnace; and the partly open top adopted for taking off the gas in such cases required the suction power of a large chimney for drawing the gas down from the furnace top.

Mr. F. J. BRAMWELL observed that at Messrs. Schneider's works an exhausting fan had been adopted to aid the chimney in drawing down the gas from the partly open furnace top; and he considered the use of a fan was decidedly the right way to draw off the gas, and thought the gas should also be washed in order to free it from dust before it was made use of for heating purposes.

Mr. T. J. Perry understood the exhausting fan that had been tried at Messrs. Schneider's works had been discontinued there, and that it had been found that a tall chimney of great capacity was practically more efficient for drawing off the waste gas from the blast furnaces.

The President enquired whether the exhausting fan was not employed at some of the French ironworks for drawing off the gas from the blast furnaces.

Mr. F. J. Bramwell believed that was the case, and that the plan of washing the gas after drawing it off had also been carried out there.

Mr. E. A. Cowper explained that the French plan that had been mentioned of washing the gas drawn off from blast furnaces, which was very effective, consisted in passing the gas through a very long horizontal pipe of D section, with the round side uppermost ⌓, and the bottom open, except that it was sealed by water contained in a long shallow trough, considerably wider than the pipe, thus forming a long water joint, and affording the greatest facility for removing the dust from the bottom of the trough without any stoppage.

Mr. G. Thomson thought there would be a deposit of tar in the gas from furnaces using raw coal alone, which might cause some trouble.

The President moved a vote of thanks to Mr. Beckton for his paper, which was passed.

The **President** proposed a vote of thanks, which was passed, to the Local Committee, the Chairman Mr. Walter M. Neilson, and the Honorary Local Secretary Mr. J. Wyllie Guild, for the excellent arrangements they had made for the meeting of the Institution in Glasgow; and also to the Lord Provost and the members of the City Council for their courtesy in accompanying the Members over the Water Works at Mugdock on the previous afternoon; and to the various Railway Companies for the facilities they had kindly afforded to the Members for attending the meeting in Glasgow and the Excursions in connection with the meeting.

A cordial vote of thanks was then passed to the President for his kind exertions in promoting the success of the meeting of the Institution in Glasgow, and the hearty welcome he had secured for the Members on the occasion.

The Meeting then terminated. In the afternoon the Members visited the Govan Iron Works, the Parkhead Forge, the Locomotive Works of the Edinburgh and Glasgow and the Caledonian Railways, and the Hyde Park Locomotive Works. A large number of engineering and shipbuilding establishments and other works were also opened to the inspection of the Members during the days of the meeting.

In the evening the Members and their friends dined together in the Queen's Rooms, in celebration of the meeting of the Institution in Glasgow.

On Thursday, 4th August, the Members visited Messrs. Napier's and Messrs. Tod and Macgregor's Ship Building Yards at Govan, and witnessed the operations of the Steam Dredgers upon the Clyde, being conveyed down the river by a special steamer. The Members afterwards proceeded up Gareloch, on the invitation of the President, to his residence at Shandon, where they were most hospitably received and entertained by the President; and in the evening they returned to Glasgow by the special steamer.

On Friday, 5th August, an Excursion was made by the Members from Glasgow to visit the works of the Loch Katrine Water Works at Loch Vennachar and Loch Katrine, passing through the Trosachs and returning by Loch Lomond, where they were handsomely entertained by the Local Committee.

PROCEEDINGS.

3 November, 1864.

The **General Meeting** of the Members was held in the Lecture Theatre of the Midland Institute, Birmingham, on Thursday, 3rd November, 1864; **Edward A. Cowper**, Esq., Vice-President, in the Chair.

The **Chairman** announced that the subject of the continued inefficient state of the Patent Office had been under the consideration of the Council, and the following Memorial to the Lord Chancellor had been prepared, and would lie for the signature of Members at the close of the Meeting.

(*Copy of the Memorial.*)

TO THE RIGHT HONOURABLE THE LORD WESTBURY, LORD HIGH CHANCELLOR.

We, the undersigned, Officers and Members of the Institution of Mechanical Engineers, being interested in the due and efficient working of the Patent Law Amendment Act of 1852, beg most respectfully to call your Lordship's attention to the report presented to the House of Commons by its Select Committee, appointed on 9th May 1864, "to enquire as to the most suitable arrangements to be made respecting the Patent Office Library and Museum;" and to represent to your Lordship the great desirability that immediate steps should be taken for carrying out the conclusions arrived at by the Committee on the evidence, and embodied in their report: namely, in effect, that a proper Patent Office and Library, with accommodation for a collection of models of inventions, should be provided on the site named in the neighbourhood of Chancery Lane, and that the expense attendant thereon should be defrayed out of the surplus income of the Patent Office.

We further beg to bring under your Lordship's notice the fact that very great loss and delay are occasioned to manufacturers, inventors, and others, by the want of a complete classification and the prompt Indexing of all inventions, whether patented or not, Foreign as well as English. Such a systematic arrangement as is needed is quite within the compass of an efficient staff of officers possessed of technical knowledge, and could be at once proceeded with; the state of inventions could then be ascertained, and the common case of several persons patenting the same thing would be avoided.

We trust your Lordship will pardon our now troubling you on these matters; but the evils arising from the present most inefficient condition of the Patent Office are a source of constant loss of time and annoyance, and we therefore seize the earliest opportunity after the publication of the report of the Committee, to bring the subject most respectfully under your Lordship's attention; and we trust that your Lordship will see fit to give such orders as will procure for the public the immediate and full advantages of the Patent Law Amendment Act of 1852, together with the erection of proper buildings for offices for the purposes of the Act.

In January 1853 certain Members of this Institution had the honour of addressing a Memorial to the then Commissioners of Patents on this subject, a copy of which we take the liberty to enclose.

November, 1864.

(*Copy of the previous Memorial.*)

To the Right Honourable **FREDERICK LORD CHELMSFORD,**
Lord High Chancellor of Great Britain;
the Right Honourable SIR JOHN ROMILLY, Master of the Rolls;
SIR FITZROY KELLY, Her Majesty's Attorney General;
and SIR HUGH McCALMONT CAIRNS, Her Majesty's Solicitor General.

The Memorial of the undersigned Officers and Members of the Institution of Mechanical Engineers humbly showeth:

That it appears to your memorialists that a largely increased accommodation is urgently required for the numerous inventors, engineers, and others, who daily consult the official documents and the valuable free Library of the Great Seal Patent Office, and who desire to inspect the instructive models collected by the Superintendent of Specifications, to which additions have been continually offered from all parts of the United Kingdom.

That although recent alterations in the laws affecting patents have stimulated enquiries in every branch of knowledge connected with industrial arts, and the publications of the Commissioners have largely facilitated such investigations, yet the full benefit of these excellent measures cannot be realised so long as only the present small apartments are devoted to this national undertaking.

That the present Library is the only one in the United Kingdom in which the public have free access, not only to the records of the patents and inventions of this country, but also to the official and other documents relating to inventions contributed by numerous foreign governments, who have liberally responded to the desire of the Commissioners to promote international relations for the improvement of manufactures by the encouragement of inventions.

That it cannot but be a matter of regret that, while a surplus already large is continually accruing from the fees paid for patents in this country, the buildings devoted to the purposes of the Patent Office are insufficient in themselves, and contrast most unfavourably with those of foreign states.

Your memorialists therefore pray that you will be pleased to take such steps as may seem to you advisable for the erection and maintenance of a central commodious Patent Office worthy of this country, where ready access may be had to a Library, Reading Room, and Museum, furnished with the papers, books, and models indispensable to the right direction and advance of British Industry.

January, 1853.

The Minutes of the last Meeting were read and confirmed.

The CHAIRMAN announced that the President, Vice-Presidents, and five Members of the Council in rotation, would go out of office in the ensuing year, according to the rules of the Institution; and that at the present meeting the Council and Officers were to be nominated for the election at the Anniversary Meeting.

The following Members were nominated by the meeting for the election at the Anniversary Meeting:—

PRESIDENT.

ROBERT NAPIER,	Glasgow.

VICE-PRESIDENTS.

(Six of the number to be elected.)

JOHN ANDERSON,	Woolwich.
CHARLES F. BEYER,	Manchester.
WILLIAM CLAY,	Liverpool.
THOMAS HAWKSLEY,	London.
ROBERT HAWTHORN,	Newcastle-on-Tyne.
EDWARD HUMPHRYS,	London.
SAMPSON LLOYD,	Wednesbury.
HENRY MAUDSLAY,	London.
JOHN RAMSBOTTOM,	Crewe.
C. WILLIAM SIEMENS,	London.

COUNCIL.

(Five of the number to be elected.)

PETER D. BENNETT,	Westbromwich.
DANIEL K. CLARK,	London.
EDWARD A. COWPER,	London.
GEORGE HARRISON,	London.
THOMAS HAWKSLEY,	London.
EDWARD JONES,	Wednesbury.
WALTER M. NEILSON,	Glasgow.
CHARLES P. STEWART,	Manchester.
JOHN VERNON,	Liverpool.

The CHAIRMAN announced that the Ballot Lists had been opened by the Committee appointed for the purpose, and the following New Members were duly elected:—

MEMBERS.

JOHN COWANS,	Carlisle.
JOHN CRAIGIE HALKETT,	Edinburgh.
THOMAS C. HIDE,	London.
WILLIAM WILSON HULSE,	Manchester.
EDWARD HUTCHINSON,	Darlington.
WILLIAM KIRTLEY,	Derby.
GEORGE LINDSLEY,	London.
WALTER MACFARLANE,	Glasgow.
ARCHIBALD FRANCIS MACNAB,	Birmingham.
LAWRENCE THOMSON MCEWEN,	Middlesbrough.
JOHN WILLIAM MIERS,	London.
JOSHUA LLEWELYN MORGAN,	Aberdulais.
FREDERICK FRANCIS OMMANNEY,	Manchester.
BENJAMIN LANGFORD FOSTER POTTS,	London.
JOSEPH D'AGUILAR SAMUDA,	London.
CHARLES TENNANT,	London.
WALTER EVERS WARDEN,	Birmingham.

HONORARY MEMBERS.

JOHN TENNANT,	Glasgow.
FALKLAND SAMUEL THORNTON,	Birmingham.

The following paper, communicated through Mr. Frederick Levick of Blaina, was then read:—

DESCRIPTION OF A COAL CUTTING MACHINE.

By Mr. THOMAS LEVICK, of Blaina Iron Works.

The substitution of machinery for manual labour in our various manufactures and industries, the gradual development of railways, and the application of steam to navigation, have increased in a wonderful manner the demand for coal, that being the chief agent in the production of the motive power in all these cases. In the early periods of the working of the coalfields the produce of coal was very limited, the only means of conveying it from the pit to the shipping port being on pack horses carrying only 3 cwts. each, which were succeeded by the cart, increasing the load to 17 cwts. But by the introduction of railways the annual produce and consumption of coal in Great Britain was raised in 1855 to 64 millions of tons, in 1859 to 70 millions, and in 1860 to 80 millions; and according to Mr. Hunt's returns it has now reached the enormous quantity of nearly 90 millions of tons per annum.

Although coal has thus been so useful in promoting and extending the use of machinery, machinery has not yet returned the compliment by its application to the working of coal; it has only made various futile attempts, and only within the last year or two have any really practical attempts been made to lessen or supersede manual labour in working coal: the working or getting may in fact be considered to remain still in the same condition as in the pack-horse age. Machinery has certainly aided the increased production of coal by winding and pumping engines and by inclines above and below ground; but this kind of machinery has only facilitated the movement of the coal after it has been wrought by the collier. The actual working or getting it from the position in which it has been deposited in the mine ages ago is still accomplished only by tools of the most primitive kind, plied by the strong arm of the sturdy collier under the most disadvantageous circumstances; for he has to wield the pick in a stooping or lying position, most unfavourable to the application of his muscular force, and this frequently in an atmosphere not only not remarkable for its purity but sometimes of a temperature as high as 80° to 90° Fahr.

The constant but gradual increase of temperature in penetrating the earth's crust, which takes place at the rate of about 1° Fahr. to each 60 feet of depth is well known. In the Monkwearmouth Colliery, the depth of which is 1800 feet, the temperature is 80°; and this is considered to be as high as is consistent with the great bodily exertion necessary in the operation of coal mining. There is also an additional augmentation in the temperature of deep mines consequent on the increased density of the air, and this is about 1° for every 300 feet of depth. Certain portions of the coal in the deeper coal basins lie at depths approaching and even exceeding 4000 feet; and the temperature of the air at this depth according to the foregoing data would be 79° higher than at the surface, 66° being due to the depth and 13° to increased density of the air. The computations therefore of the duration of the coalfields, as has been pointed out by Sir William Armstrong, require a considerable reduction in consequence of the impracticable depths at which portions of them are situated; and any means of increasing the practicability of working at these depths by the application of machinery becomes consequently a question of serious importance in reference to the duration of the coalfields, in addition to the advantages in economy of cost and time of working and in saving waste of material that are incident to the substitution of machinery for hand labour.

Many attempts have been made during a century past to construct coal cutting machines. One of the earliest was that of Michael Menzies in 1761, consisting of a pick fixed on the axle of a pulley placed near the face of the coal, to which a reciprocating motion was given by means of a chain passing round the pulley and connected with a steam engine at the surface, the pick performing the operation of kirving or holing. He also invented a pick machine to be worked by hand.

In 1830 a battering ram for coal mines was proposed by William Wood. This was a heavy ram fixed in a sliding box acting on a wedge, the ram being worked backwards and forwards by manual labour.

The next to be noticed is a plan in 1843 consisting in applying rotary saws or picks driven by a winch or an engine for the purpose of severing blocks of coal from the surrounding mass. This was one of the first attempts for using rotary cutters, and the arrangements were complicated.

In 1846 a plan was proposed by Mr. W. H. Bell for suspending a heavy pick or chisel by a chain from a bar running along the face of the work at the roof, so as to be swung by hand against the coal.

In 1852 a machine was applied by Mr. W. D. Hedley, similar in its action to a planing machine, having a cutting tool projecting from the side of a carriage running on a railway, and the tool was made to cut deeper and deeper into the face of the coal by repeatedly traversing the carriage, and setting the tool at each successive cut to project more and more beyond the side of the carriage. There were holes in the machine at different heights for altering the tool according to the different heights at which the coal has to be cut.

About the same time a plan was proposed by Mr. C. H. Waring, in which reciprocating or revolving cutters are worked by compressed air or steam. The reciprocating cutters have somewhat the motion of planing or slotting machines, but the rotary cutters are fixed in the circumference of a wheel and act like a circular saw. The machine is arranged to cut either vertically or horizontally. The apparatus for applying the power is mounted on the frame of the machine, and consists of an oscillating cylinder worked by compressed air or steam.

In 1861 a pick machine to be worked by hand was proposed by Messrs. Ridley and Rothery, the pick working horizontally and vertically, and both motions being upon fixed axes; and about the same time a hand machine was proposed by Mr. Donisthorpe, in which the tool was a bar mounted on grooved rollers, giving it a rapid motion forwards and backwards.

The above are some of the principal attempts up to that time to work coal by machinery. They may be divided into reciprocating picks, sliding or planing picks, and rotary saws or cutters; none of them however have continued in practical use. The principal practical difficulty in the application of machinery to coal cutting is the confined space it is required to work in. Most of the machines above referred to occupy too much space and are generally too complicated for application in a coal mine; and machines made to be worked by hand, on account of the friction of the mechanism and the cumbrous arrangement, absorb too much manual labour to give them much or any advantage over the pick worked by the skilled collier.

Not until the last two or three years has anything practically useful been accomplished in the application of machinery to coal cutting; and Messrs. Donisthorpe Firth and Ridley's machine working at the West Ardsley Colliery near Leeds was the first machine which may be safely said to have demonstrated the practicability of cutting coal by machinery. This was one of the class of machines working with a pick, which was driven by a cylinder worked by compressed air; and it was followed by another machine, which introduced a trunk arrangement of the driving cylinder, so as to shorten up the connecting rod, thereby considerably shortening the machine, and enabling it readily to traverse the quick curves of mine tramroads, thus removing a serious practical difficulty previously experienced. Both these machines have been successful in performing one operation in coal cutting, namely "holing" or undercutting a seam of coal horizontally, and on a true plane or nearly so. But as they were constructed only to cut a groove horizontally, or rather parallel to the plane of the tramway, they were not adapted to meet the cases of inclined seams, so frequently occurring in practice; and as they were also limited to the horizontal undercutting, all vertical cutting that was required in the operation of getting the coal had to be done by hand work. These machines were inapplicable to driving headings; and for that purpose a modification of them has been made, having two pairs of vertical picks, one pair on each side of the machine, and each pair consisting of one pick working upwards vertically from the bottom and the other working downwards vertically from the top, so as to make the two cuts meet one another. The undercutting however in driving the headings was still required to be done by the hand of the collier.

In order that a machine may be generally applicable to coal cutting, it should be capable of cutting in any direction, so as to work the "dip" or the "rise" or cut the vertical cuts. To do this, and at the same time to retain a simple form of machine, since complex machinery would be very objectionable underground, presented great difficulties; but these have now been entirely overcome in the coal cutting machine forming the subject of the present paper, which is the invention of Mr. James Grafton Jones of Blaina. In this machine the axis of the pick is carried in a revolving headstock, by which it is capable of being turned into any desired position by merely turning a handwheel at the end of the machine, the relative position of the pick and the air cylinder which works it remaining always the same. By this means the pick can be worked in any plane, either vertical, horizontal, or at any inclination; and it is thus enabled to cut the coal vertically in driving headings, and horizontally in holing, or in any inclined direction for working the dip or the rise when the seam of coal does not lie horizontally. Headings may thus be driven or any of the ordinary operations in the getting of coal or other minerals may be performed by the machine.

The machine is shown in Figs. 1, 2, and 3, Plates 82 to 84; Fig. 1 is a side elevation, Fig. 2 a longitudinal section, and Fig. 3 a plan.

The air cylinder A, Figs. 1 and 2, is placed horizontal, and is cast in one piece with the bed of the machine; and the piston B is forged solid upon the piston rod C. The lever pick D is keyed upon the transverse axis E carried in front of the cylinder A; and on the axis is a crank arm F, to which the piston rod C is connected by means of the slotted head screwed into the end of the rod, as shown in Fig. 2. The axis E is carried in bearings G G cast upon the rotating headstock H; and this headstock is capable of being turned round in its bearings I I, by means of the handwheel J fixed on the shaft of the pinion K, Fig. 1, which gears into teeth on the headstock H. The pick D can thus be turned so as to cut the coal at any inclination whatever, the piston B turning in the cylinder when the headstock H is rotated; and when the pick is adjusted for working at any desired inclination, the axis E can be locked in that position by means of a pin passing through one of the holes in the handwheel J.

The slide valve L, Fig. 2, by which the compressed air is admitted to the cylinder A, is worked in one direction by the piston B, which on completing its back stroke strikes against the tappet rod M; this rod works through a stuffing-box in the back cover of the cylinder, and is connected to the lever N, the other end of which is connected to the slide valve stem. When the tappet rod M is struck by the piston, it moves the valve L into the position for admitting the compressed air to the back of the piston, for striking a blow by the pick. The valve is retained in this position until the blow has been struck, by means of a spring catch O, which is connected by a rod to the treadle P. An india-rubber spring R passes round the handle S formed on the lever N, and is attached by means of an adjustable joint to the platform T, on which the man working the machine is carried. When the treadle P is depressed by the man's foot, it releases the catch O, and the india-rubber spring immediately moves the slide valve so as to admit the compressed air to the front of the piston for making the back stroke; and another blow of the pick is then given by the piston striking against the tappet rod M. As the work progresses the machine is moved forwards by the handwheel U, which communicates motion by the bevil wheels V to the carrying wheels W of the machine.

From this description it will be seen that, at whatever inclination the coal may lie, the pick is easily put to work at that exact angle, whether to the rise or the dip. It may also be easily put to work at any part of the thickness of the coal, whether it be desired to hole at the bottom or at the top of the measure, or at a parting in the middle or any other portion of the seam, by simply shifting the pick D, Fig. 1, to a greater or less distance upon the axis E on which it is keyed. Figs. 6, 7, and 8, Plate 86, illustrate the working of the machine, showing the pick in the position for holing, and also for making a vertical cut either downwards or upwards, as in driving headings. The position of the man working the machine is also shown, kneeling on the small platform at the tail of the machine, with his foot upon the treadle for releasing the slide valve, and holding the handwheel for advancing the machine between each stroke of the pick.

This machine when holing in the coal cuts a groove 3 feet deep, 2 inches wide at the face and 1½ inch at the back; whereas a collier requires for effecting the same purpose to make a groove or rather excavation 10 to 12 inches wide or even more at the face, and tapering to the back. In doing this the collier is exposed to one of the most frequent and unavoidable dangers of the coal mine, by the large lump of coal breaking off and sliding down suddenly without warning, before he has completed his task.

The machine is calculated to work at the rate of 70 to 80 strokes per minute; and the one at work at the High Royd Colliery, Barnsley, under disadvantageous circumstances and in the hardest coal in the district, holes from 9 to 10 yards length per hour, 3 to 3½ feet deep, including stoppages. In order to make the machine thoroughly effective, it is necessary that it should be on a good rigid road; but at this colliery it is working on the ordinary tramplate road loosely laid. The pressure of air at which it is worked is 30 to 35 lbs. per square inch. In the same seam of coal the collier does only 4 to 5 yards length of holing for a day's work, in place of the 90 to 100 yards done in 10 hours by the machine, the latter thus accomplishing fully twenty times the work that the collier can do by hand in the same time.

A second machine has just been put to work at the Oaks Colliery in the same district, in which an improvement has been made by the addition of a steadying apparatus, consisting of a tail piece which carries a pair of heavy rollers, as shown in plan in Fig. 4, Plate 85;

these rollers rest upon the tram rails and keep the machine steady under the vibration caused by the blows of the pick when striking laterally in holing. This tail piece follows with the machine when moving in a straight line; and it has the effect of lengthening the wheel base of the machine, and considerably reduces the lateral vibration on the road caused by the powerful blow of the pick when holing. It is readily detached when required to go round the short bends of the mine; and also when driving headings it is not required, as the pick is then working vertically. The machine at the Oaks Colliery holes at the rate of 14 to 15 yards length per hour, to a depth of 3½ feet, the number of strokes averaging from 60 to 70 per minute, and the pressure of air being 35 to 37 lbs. per square inch. The road in this case is a railroad thoroughly well laid.

These machines are also well adapted to work in the ironstone shales and to quarry Bath stone; indeed the pick would work in anything softer than its own point.

The use of compressed air for working underground machinery is not new, though it is only recently and since the introduction of coal cutting machinery that it is being more extensively employed. The first practical employment of it in this country was at the Govan Colliery near Glasgow in 1849; the machinery was erected by Messrs. Randolph Elder and Co., and a description of it was read before this Institution at the Glasgow Meeting in 1856 (see Proceedings Inst. M. E., 1856, page 145). At the Haigh Colliery near Wigan two air-compressing engines were also employed, the air being compressed to 120 lbs. per square inch, and carried down a shaft 234 yards deep, and to a distance of 500 yards from the bottom of the shaft. The engines worked by the compressed air at this colliery and at the Govan Colliery were employed for winding underground.

A peculiarity attendant upon compressing the air is the heat developed during compression, which increases rapidly with the pressure. Thus air, which at the atmospheric pressure of 15 lbs. is at 32° Fahr., would be raised to 110° by being compressed to 30 lbs. per square inch; and at 120 lbs. per square inch, the effective pressure in the Haigh engines, the theoretical temperature would be about 450°. A special provision to meet this circumstance is mentioned hereafter. An inconvenience in working these compressed-air engines was the liability of the air passages and exhaust pipes to become clogged with ice, in consequence of the water suspended as moisture in the air being frozen by the cold produced in the sudden expansion of the exhaust air. This is avoided in the coal cutting machines by making the slide valve with sufficient inside lap to cause the exhaust air to escape slowly at each stroke, thereby preventing its sudden expansion; and this arrangement, combined with the concussion caused by the stroke of the pick, prevents the exhaust passages becoming clogged with ice. In an air engine at Dowlais, when the air was escaping under a pressure of 15 lbs., the temperature of the exhaust air was 29° Fahr.; and the greater the pressure, the greater will be the cold produced in expansion.

There is a loss of power in air-compressing engines, arising from leakage and friction in the air pipes, and the mechanical power lost in the form of heat when the air is compressed. The loss from leakage and friction is very small, and if the joints are good, that from leakage will be inappreciable; but the loss from the escape of heat is great. The cylinder in which the air is compressed gets so hot that it is necessary to keep it surrounded with water, the temperature increasing with the pressure to which the air is compressed; and on the other hand when the compressed air has done its work and is allowed to escape, a degree of cold is produced which freezes any moisture that there may be in the exhaust passages. By the compression of the air its capacity for heat becomes diminished; consequently a portion of the latent heat already contained in it at its natural pressure is developed in the form of sensible heat, and this is absorbed by the cylinder and the surrounding water. The air itself does not get sensibly hotter, since only its capacity for heat is changed by the compression, while the excess of heat developed by its compression is rapidly absorbed by the surrounding metallic surfaces which conduct it away. When this air has done its work and expands again to its original pressure, its original capacity for heat returns; and the quantity of heat then contained in it not being sufficient for maintaining the same temperature in its expanded form, it consequently draws heat from the surrounding bodies, thus producing cold. The amount of heat thus absorbed in the act of expansion is the exact equivalent of that which is developed during compression; but the heat developed in compression being lost by conduction, the amount of power equivalent to it is also lost.

Fig. 5, Plate 85, shows a longitudinal section of the air-compressing engine, of a size suitable for working four to six coal cutting machines. It consists of two cylinders, one the steam cylinder and the other the air cylinder, fixed horizontally on the same bedplate, the piston rod of the steam cylinder being directly attached to the piston rod of the air cylinder. The steam cylinder A is 16½ inches diameter and 3½ feet stroke. The air cylinder B is surrounded by water to keep it cool. The compressed air passes through the delivery valves C C into the pipe D leading to the mine. The inlet valves are fixed on the side of the air cylinder, and are similar to the delivery valves. The slide valve of the steam cylinder is worked by a tappet, as there is no crank or flywheel to the engine. The speed of the engine is regulated according to the number of the coal cutting machines at work: when all six machines are at work, the speed of the piston is from 250 to 300 feet per minute.

The effect produced upon the ventilation and temperature of the mine by the supply of air from the discharge of the coal cutting machine may now be considered. When the machine is working at 60 blows of the pick per minute, it will discharge 24 cubic feet of air per minute at a pressure of 45 lbs. per square inch, which by expansion becomes 72 cubic feet of air at the atmospheric pressure and at a temperature below freezing point. Taking the quantity of air passing along each face of work in the mine at an average of 6000 cubic feet per minute at a velocity of 4 feet per second, the quantity of air discharged by each machine would be only 1¼ per cent. of the whole amount. Supposing the temperature in the mine, as at Monkwearmouth, to be about 80° Fahr., it would be reduced only 1° when thoroughly mixed, but it would be considerably cooler round the point of issue. The ordinary ventilating current has frequently had to travel considerable distances, and has acquired a great deal of impurity and a high temperature before it reaches some of the faces of work. But supposing three or four machines to be employed along each face, the current instead of becoming impure would retain its purity and become cooler.

A collier when at work breathes heavily, and inhales about 28 cubic feet of air per hour, and exhales about 1 cubic foot of carbonic acid in the same time. One coal cutting machine may be said to save the work of 20 colliers, who would inhale 600 cubic feet of air per hour; while the machine supplies 4320 cubic feet per hour of cold and pure air at the place where it is most required.

The firedamp in a mine having only half the specific gravity of air is very apt to float above the passing current of air, instead of mixing with it, especially where there is any unevenness in the roof forming cavities in which the firedamp can lie stagnant. The violent agitation however produced by the discharge of air from the coal cutting machine will aid materially in the intermixture of the gas with the current of air, and the discharge of air from the machine may be directed to any particular point, as desired.

The advantages of cutting coal by this machine may be summed up as follows:—

1st. The saving of a large percentage of small coal in the process of holing, and a corresponding increase in the proportion of large coal obtained.

2nd. The economy in the cost of getting the coal.

3rd. The improvement in the ventilation and temperature at the working points.

4th. The facility with which headings may be driven and ventilated, the machine itself supplying air sufficient for several men and at a low temperature. The machines being well adapted for driving headings, collieries may be opened and won to their outside boundaries in a much shorter time.

5th. The saving of life and limb to the collier, by removing him from the most perilous portion of his occupation, that of holing or undercutting the seam of coal.

6th. The power of carrying the working into the deeper seams of coal, which lie at so high a temperature as to present serious difficulty in the way of performing the severe labour of cutting the coal by hand work.

Mr. F. Levick exhibited a model of the coal cutting machine, illustrating the action of the pick in cutting the coal at any inclination by means of the revolving axis carrying the tool.

The Chairman remarked that the application of machinery to coal cutting was a subject of great importance, and there could be no doubt that ultimately coal cutting machines would greatly assist manual labour, by performing the most difficult and dangerous work of undercutting the coal. In the machine described in the paper just read, the principal feature appeared to be the arrangement by which the tool was turned round to work at any inclination, thus affording the means of cutting the coal at any angle. The machine was otherwise similar to that of Messrs. Donisthorpe Firth and Ridley, which was now working at the West Ardsley Colliery near Leeds, and he believed that was the first instance in which machinery had been successfully brought into practical operation for coal cutting by the use of compressed air actuating a pick; the machine was capable of being worked in any part of the mine by compressed air supplied to it from an engine at the surface.

Mr. W. Mathews had not had an opportunity of seeing coal cutting performed by machinery, but was satisfied that if the application of machinery to that purpose could be practically accomplished it would prove a most important benefit in coal mining. The recent struggle with the colliers in South Staffordshire was a sufficient proof of the necessity of adopting machines for cutting coal in place of manual labour.

Mr. Sampson Lloyd enquired what effect the great variety in the thickness of the seams of coal in different districts would have upon the applicability of the machine now described; and whether, if successfully employed in one district with a certain thickness of seams, the same machine could be made equally applicable in another where the seams were of a very different thickness.

Mr. C. Cochrane thought one of the difficulties attendant upon different thickness of seam would be felt in applying the coal cutting machine in South Staffordshire, owing to the different method employed in cutting the Thick coal. In undergoing the Thick coal the practice was to cut away a thickness of 2½ feet, and this was all sacrificed as slack, and had to be excavated in order to allow the collier to go in under the coal for performing the holing, which was carried to a depth of 10 or even 20 yards in from the face. The machine in undercutting the coal to a distance of 3 feet in from the face excavated a groove only a few inches thick, which he thought would be found quite inadequate in the Thick coal to allow of breaking the coal down afterwards. If the present system of working were carried out, the machine would be required to be arranged so as to excavate a thickness of 2½ feet, and afterwards go into the excavation so made and undercut the coal still further from the face; and he thought there would be some difficulty in using the machine in that way. Before adopting the machine, information was needed respecting its durability, as to whether that had been fully tested by actual working; and also in reference to the total outlay for plant in cutting coal by a machine of the size shown in the drawings.

Mr. F. Levick explained that the machine excavated only 2 or 3 inches thickness of coal in undercutting the coal to a distance of 3 feet in; and the coal so undercut could then be benched down for a height of 2½ feet, if desired; after which the machine could go under and proceed with the holing 3 feet further in, and so on to any extent of undergoing that might be desired, since the machine was made low enough to enter into any space 2½ feet high, and could thus go under the coal wherever a collier could work in the ordinary system of holing. The great advantage however of the machine over the collier was that, while the whole thickness of 2½ feet was converted into slack by the collier, in order to cut an excavation large enough to admit him to go under, the machine converted only 2 or 3 inches thickness into slack, and the remainder of the 2½ feet thickness was obtained in the form of good serviceable coal. The machine shown in the drawings was low enough to work in a height of only 2½ feet; but it could be made considerably lower by diminishing the size of the carrying wheels and otherwise modifying the construction. In undercutting the coal, the axis of the pick was turned so as to bring the pick into its lowest position, enabling the pick to excavate the coal as low down as on a level with the rails.

Mr. W. HADEN did not see what need there was to undergo the coal to a greater depth than 3 feet from the face before benching it down. It was true that was not in accordance with the very antiquated mode of working the Thick coal which was still adhered to in the South Staffordshire district; but he did not think there was any real necessity for working the Thick coal in a different manner from that adopted in thin seams, as regarded the mode of holing, and the machine might just as well be employed in the Thick coal for undercutting to a depth of 3 feet, after which the coal so undercut could be benched down to any height that was desired. He enquired whether the machine could cut vertically, so as to cut down the sides of a block of coal after undercutting it, which would then allow of benching the coal down easily in the case of driving a heading.

Mr. C. COCHRANE thought the machine was best applicable for undercutting thin seams of coal, where the creeping of the roof had the effect of breaking down the coal as the work proceeded. In applying this machine however to the lower portion of the Thick coal there would be no such creep, the thickness of coal above being so great as to prevent any practical deflection; and thus the difficulty would arise as to how the coal so undercut could be broken down; and furthermore how, if that were effected, the large masses of coal could be conveniently broken up into pieces sufficiently small for a man to lift. One advantage of the deep excavation made by a collier in holing the Thick coal, notwithstanding the quantity of slack produced, was that the act of dropping the seam above broke the coal up into masses which did not require much further trouble to make them small enough to be handled in the usual way.

Mr. F. Levick explained that, by turning the pick round so as to work vertically, the machine would cut the coal vertically in the same manner as it performed the holing. It was not intended however for breaking up the large masses of coal after they were benched down, and that operation as well as loading the coal into the trams would have to be done by hand labour, as at present.

Mr. F. Smith observed that it appeared from the explanations which had been given that the machine was as applicable as manual labour to the purpose of undercutting the coal, to the extent of even 2½ feet thickness, by excavating two horizontal cuts at top and bottom of that thickness, and then benching down the coal between; and the difference between the two modes of holing was the important practical advantage obtained with the machine in getting nearly all that thickness of coal in the useful form of lump coal, instead of its being all converted into slack as was done by the collier.

Mr. W. Mathews enquired what was the thickness of the seams of coal at the collieries where the machine had been adopted, and what was the character of the coal cut, and the lay of the seams. In working seams of coal up to 4 feet thick, if the holing were carried in to a distance of 3 feet from the face by the machine, that would no doubt allow of benching down the remaining thickness of the seam: but with the South Staffordshire Thick coal of 30 feet thickness he thought a holing extending only 3 feet in under the coal would not be far enough to allow of bringing down the greater thickness that was usually benched down at a time, and it would be necessary for the undergoing to be carried further in. Moreover there was a great difference between hard and soft coal, as to the success with which it could be worked by a machine: for he understood that the trials made by Mr. Nicholas Wood with a coal cutting machine at his collieries in Durham had proved successful with the soft coal, but not with the hard coal, as the machine worked so much slower in the hard coal. The lay of the seams also, instead of being always horizontal, was frequently at an inclination, the slope of which was varied by waves in the seams; and in many localities the course of the seams was interrupted by faults. In working such seams by manual labour the collier could employ his pick in such a manner as to meet the requirements of any case that might arise; but a machine was not so readily adapted to all varieties of circumstances.

The **Chairman** said the seams of coal worked by the machine at the West Ardsley Colliery were about 5 feet, 3 feet, and 2 feet 9 inches thick, and the machine was equally applicable for cutting the coal in all of them. The machine used in that case was smaller than the one shown in the drawing, and could cut the coal only horizontally or vertically, but not at an inclination. The earlier machines had been rather too small, but they might be made of any size that was most suitable for the mine in which they were to work.

Mr. **F. Levick** explained that, whatever might be the inclination at which a seam of coal lay, it could be cut with equal facility by the machine, since the pick worked either horizontally or vertically or at any inclination between those extremes, with equal readiness in all positions. In the case of a colliery in Glamorganshire, where the dip of the coal was at an inclination of 45°, it had been decided, instead of sinking a vertical shaft in the ordinary manner, to sink an inclined shaft at 45° following the dip of the coal, by means of some of these coal cutting machines which had been ordered for the purpose. As regarded the application of the machine to the Thick coal of South Staffordshire, he remembered that the plan in use many years ago for working the coal had been to work it in successive stages, commencing from the bottom and working upwards; and in places where the Thick coal was so worked, the machine would answer the purpose of undercutting in the bottom stage. In reference to the practical working of the machines, one of them had now been at work at the High Royd Colliery near Barnsley for the last three months, which was of the size shown in the drawings, and he understood had proved thoroughly successful.

Mr. S. **Bailey** had seen the coal cutting machine at work both at the West Ardsley Colliery and at the Hetton Colliery, at both of which collieries the machine was the same as that described in the paper, excepting that the latter had the important improvement of the revolving axis, enabling the pick to be worked at any inclination so as to cut the coal either in seams lying level or inclined. He had been much pleased with the working of the machines at both places, and had noted the particulars of two pieces of work that he had seen done by the machine at the Hetton Colliery, undercutting the coal in the High Main seam, which was a very hard quality. The holing was performed at three separate cuts, with a different tool each time; and in the first piece of work a length of 6 feet along the face of the coal was undercut by the machine to a depth of 2½ feet in from the face in 18½ minutes, the particulars of each cut being as follows:—

1st cut . . .	19 inches deep . .	in 9 minutes.
2nd „ . . .	5 „ „ . .	in 4½ „
3rd „ . . .	6 „ „ . .	in 5 „
Total depth of cut .	30 inches deep . .	in 18½ minutes.

In the second piece of work a length of 3 feet along the face was undercut to a depth of 3 feet in from the face in 11½ minutes, as follows:—

1st cut . . .	19 inches deep . .	in 4 minutes.
2nd „ . . .	12 „ „ . .	in 5 „
3rd „ . . .	5 „ „ . .	in 2½ „
Total depth of cut .	36 inches deep . .	in 11½ minutes.

The time noted included the time of exchanging the picks between each cut, and moving the machine back again to the starting point for each separate cut. From these specimens of its performance he was very well satisfied with the working of the machine, and was confident that its adoption in any district would be attended with very considerable advantage in coal mining.

Mr. T. **Levick** had seen one of the new machines started to work only two days previously at the Oaks Colliery near Barnsley, in a seam of coal about 5½ feet thick, where it was working along a road laid in the direction of the dip of the coal. That was the first time that one of the machines had been applied upon an inclined road, and there was rather a difficulty in keeping the machine back in working; it had a tendency to run forwards down the incline of the road, which somewhat interfered with the pick clearing itself readily from the coal after it had struck the blow, and the pick was apt to jam itself in the groove it had cut. Notwithstanding this drawback however the machine on that occasion undercut a length of 14 feet in 7 minutes at the first cut, to a depth of 15 inches in from the face. The machine at the High Royd Colliery near Barnsley had now been at work for some months, and it was calculated that it did the work of rather more than twenty colliers; the coal it was working in was 8½ feet thick at that colliery.

Mr. F. Smith enquired whether the coal was benched down after passing the machine once along the face and undercutting once with the pick.

Mr. T. Levick replied that the machine was passed twice or three times along the work, until the coal was undercut to the depth of 3 feet in. After making the first cut the machine was taken back to the place from which it started, and the first tool was removed and replaced by a longer pick rather thinner at the point; this did not cut the groove any wider than the 2 inches excavated by the first cut, but only deepened it. After the undercutting had been carried to the depth of 3 feet along the whole length of the cut, the coal was benched down.

Mr. J. E. Swindell asked whether in a seam as thick as 5 feet the coal could be benched down with only so small a thickness as 2 inches cut out at the bottom by the machine.

Mr. T. Levick replied that an instance of that sort had occurred at the High Royd Colliery, where the coal could not be benched down with only 2 inches thickness excavated in undercutting.

Mr. J. G. Jones said that in such a case it was intended to put on a cleaver or axe instead of the pick, and fix it for working on the upper end of the axis of the machine, cutting downwards in an inclined direction towards the first holing, so as to cut out a wedge-shaped block of coal; for it was found that in benching down so much as 5 feet thickness of coal at once, the excavation of only 2 inches width made by the pick of the machine was not enough to allow so thick a block of coal to break off, or if it did break off it lodged and could not be readily got out. By cutting out a wedge of coal however with the cleaver, the holing was made as wide at the face as was done by the collier, with the important advantage that the piece of coal so cut out by the machine was obtained as good serviceable lump coal, instead of being all broken up into slack in the process of holing by manual labour.

Mr. J. Fernie enquired how the forward movement was given to the machine, for advancing it as the work progressed.

Mr. T. Levick explained that the forward motion was given by the handwheel on the top of the machine, geared to the carrying wheels, by means of which the machine was advanced by hand the required distance after each stroke of the pick. Before advancing the machine however after each stroke, it was first drawn back slightly by the handwheel, so as to ease the pick out of the cut, and allow of the return stroke being made readily; the action thus produced was similar to that of a collier working a pick by hand.

Mr. J. E. Swindell asked in what manner the machine would be put to work for driving a heading of 3½ feet square, in front of the machine itself.

Mr. T. Levick said for such a purpose the pick was started cutting vertically downwards, being fixed first on one end of the axis and afterwards on the other, so as to cut a vertical groove on each side of the heading. The axis of the pick was next rotated, so as to make the pick cut horizontally, and the machine was drawn back to the full length of the pick, which then cut a horizontal groove at bottom and top of the heading, so that the cubical block of coal was cut on all four sides, and held only at the back, and was readily broken off and removed.

Mr. G. Addenbrooke had seen the machine at work at the West Ardsley Colliery more than a year and a half ago, and it appeared to be doing its work admirably, irrespective of the question of cost of working. The seam of coal in which it was then working was 3½ feet total thickness, having a parting in it less than 1 foot thick in which the machine was performing the holing for getting the upper half of the seam of coal first. He enquired what was the cost of the coal cutting machine and the air engine for working it.

Mr. F. Levick replied that the heaviest part of the expense was the air-compressing engine, which however was of simple construction, as seen from the drawing; and the cost of an engine of the size there shown, with steam cylinder 16 inches diameter and 3½ feet stroke, was not more than £250. The size of steam cylinder however would of course depend upon the pressure of steam intended to be employed. The cost of the coal cutting machine was about £60 or £70, exclusive of royalty.

Mr. G. Addenbrooke enquired whether there was not rather a heavy expense in conducting the compressed air from the engine to the machine. At the place where he had seen the machine at work in the West Ardsley Colliery there was about 40 feet length of vulcanised india-rubber tubing at the machine, as the air tube was required to be flexible at its extremity, to allow the machine to move backwards and forwards; and he had noticed that there was a great deal of leakage, consequent on its working backwards and forwards over the rough floor of the mine.

Mr. T. Levick thought the leakage of air would be small, if the pipes and joints were properly constructed in the first instance. The size of the pipes necessary to convey the air to the machine was so small that the expense on that score would not be considerable. At the Oaks Colliery, where it was intended to use the machines on an extensive scale, the pipes had been made larger than would otherwise have been necessary; they were 5 inch cast iron pipes from the air-compressing engine to within 400 yards of the machine, then 2½ inch cast iron pipes nearly to where the machine was working, and thence 1¼ inch gas piping with an india-rubber hose at the end; so that practically a 1¼ inch pipe was amply sufficient for working one machine well. At the High Royd Colliery much smaller pipes were used, the pipe from the engine being only 1½ inch diameter; and a 2 inch gas pipe would be large enough for supplying two or three machines with air.

Mr. F. Smith enquired whether the air-compressing engine could be worked by the winding engine of the pit, instead of having an independent steam cylinder for the purpose. He asked also whether in undergoing the coal the point of the pick cleared its own course, in undercutting by the machine: a collier in holing gave two motions with the pick, the first being the actual striking of the blow, and the second a sort of drawing motion, drawing out the small coal from the cut.

Mr. J. G. Jones replied that it was objectionable to attach the air-compressing cylinder to the winding engine, because the interruptions in the regular working of the engine would interfere too much with the regular working of the coal cutting machine; but it might be attached to the pumping engine, if it were desired to avoid having an additional steam cylinder. The required movement for enabling the point of the pick to clear itself after each blow was given by the man working the machine, who brought the machine back a little after each stroke by means of the handwheel, so as to free the pick out of the groove; and the pick brought a small quantity of small coal out with it at each stroke.

The Chairman remarked that at the West Ardsley Colliery the exhaust air from the coal cutting machine was blown into the cut, which effectually blew out all the small coal and dust and kept the groove clean for the pick to work in. At first the air was blown in alone, and the coal at that colliery being of a dry quality, the effect was to smother the men with dust; and then a little water was blown in with the air, which completely laid the dust, while clearing out the dirt.

Mr. J. G. Jones had not found it necessary to blow in water with the air at other collieries where the machine was employed; but some coal was much more dusty than others, and in that case a little water should be used with the air for blowing out the cut.

Mr. J. E. Swindell enquired whether the saving effected in cutting the coal by the machine as compared with manual labour had been ascertained from the working of the machines at the collieries where they were in use.

Mr. F. **Levick** was not aware what was the amount of the saving effected by employing the coal cutting machines; but that there was a considerable saving was shown by the fact that at the collieries where they were already adopted it was intended to use them still more extensively in place of manual labour. Already one machine did the work of 20 or 30 colliers in holing, and he expected it would ultimately be made to accomplish even more.

Mr. G. **Addenbrooke** remarked that, even if the machine had cost more than manual labour, it would have been of the greatest advantage in the South Staffordshire district to have a number of the machines ready to be put to work during the recent colliers' strike.

Mr. J. M. **Hetherington** said a rough estimate of the saving effected by the machine might be obtained by comparing the wages paid to colliers and the cost of the machine. In Lancashire the average wages of a collier were 30*s*. per week, amounting to about £75 per year; and the cost of four machines, complete with air-compressing engine and pipes to the machines, might safely be estimated at an outlay of not more than £1000. Thus 7½ per cent. interest on the outlay would be realised upon the labour of every collier saved by the machines; and as one machine was found to perform the work of 20 men in holing, it was clear that a considerable number of men might be dispensed with by the adoption of the machine, with a large saving in the cost of getting the coal.

Mr. **Isaiah Hill** thought the question was only one of cost, as to the adoption of the coal cutting machine, since there appeared to him no doubt about its advantages over manual labour, and it had only to be considered what would be the expense of putting the machine to work and keeping it in good order. It would be particularly serviceable in mines worked on the long wall system; and where the pits had straight roads the expense of working the machine he thought need not be much; but in pits worked with gob roads for bringing out the coal through the goaf, as was commonly the case in long wall workings, there would probably be a good deal of expense involved in constantly taking up the air pipes as each gob road in succession was abandoned, and relaying them in the new roads as the working faces advanced. Notwithstanding this additional trouble however he thought the machine might be advantageously brought into use in such cases. It would also be especially applicable wherever there was the good fortune of meeting with a considerable extent of a level coal seam not interrupted by faults, in which case it might be put to work with great advantage to undercut along a great length of face, where otherwise as many as 20 men in a row might have to be employed for holing the coal. There would probably be much difficulty in using the machine in places where there were many faults, from the trouble of constantly shifting the machine to work in different positions, and the difficulty of obtaining a sufficient length of working face to render the employment of the machine remunerative.

Not only would the machine effect a great saving in undergoing the coal, by obtaining good solid coal where the collier made small slack, but this saving would be particularly important in the case of thin coal seams, say only 3 feet thick or less, in which at present the collier cut away about 18 inches thickness at the face and converted it into slack. And with regard to undergoing in the Thick coal of South Staffordshire, of which he had had experience in the workings under his charge at the Chillington Collieries near Wolverhampton, as the chief amount of labour was in the undergoing, he did not see why the machine should not be made serviceable for the purpose, by adding a longer pick if it were desired to carry the holing further in from the face before benching down the coal. The thickness of 2 inches excavated by the machine appeared to him to be in general quite sufficient for getting the coal down, as it must be a very hard coal indeed that would not break off with 2 inches of undercutting at the face carried to a depth of 3 feet in. No doubt the mass of coal benched down with only 2 inches thickness of holing, would "lie in the dirt" as it was called, that is, would remain almost in the same place after being broken down, instead of falling forwards from the seam; but it would be none the less completely broken down and loosened from the seam, and could be broken up and got out by the colliers in the usual manner. In working very hard coal, it was frequently necessary to blast it with powder, and when that was the case he suggested that the machine might be made use of for drilling the holes for the charges. The machine would also be very useful he thought for many other parts of the work done in a pit, particularly for driving small headings or gateroads; and as the quantity of small coal made by the machine was so much less than in hand labour, he thought this might all be used up in the puddling furnaces.

Mr. T. **Levick** explained that in working a very hard coal, which would not break off with only 2 inches thickness of holing, the coal was got down by putting a cleaver or axe on the machine, as had been mentioned, after first undercutting with the pick; by that means a wedge-shaped piece of coal was cut out to the height of 1½ or 2½ feet, which had the same effect as undergoing the coal to the same height by hand labour, and saved the coal instead of reducing it to slack. This had been done at the High Royd Colliery for benching down the coal in the 8½ feet seam, and the original 2 inch groove cut by the machine was afterwards widened by the cleaver to 18 inches at the face of the coal.

Mr. F. **Smith** did not see why the length of the pick should be limited to 3 feet, and he enquired whether a greater length of pick had been tried with the machine, for undergoing the coal to a greater distance in from the face. He asked also how many men were required for working the machine, and in what spirit it had been received by the colliers at the pits where it was already at work.

Mr. T. **Levick** replied that in working the machine with a long pick, as the wheels were kept close together under the body of the machine, it had a great tendency to jump off the rails at each stroke of the pick in holing; but this had now been effectually obviated by the addition of the steadying tail-piece attached behind the machine, which produced a great improvement in the steady working of the machine, preventing vibration in holing, and allowing of keeping the carrying wheels close together under the machine. The greatest length of pick yet worked by the machine was 4½ feet, but 3 feet was the longest ordinarily used. The machine required only one man or a boy to work it.

The **Chairman** said he had understood the men working at the collieries where the machine was used liked it because it brought them a constant and very abundant supply of fresh cool air into the workings. It would of course be an expensive undertaking under ordinary circumstances to keep the mine cool for the men, but with the coal cutting machine the owner of the colliery could not avoid throwing cold air into the workings. The way in which the machine had been worked at some collieries where there was a night shift was to undergo a lot of coal in the night, and then the men went down the pit in the morning to get it during the day. With regard to the great advantage and economy of the machine as compared with hand labour, it should be borne in mind that one principal reason of the superiority of the machine was that the pick when worked by the machine was guided at each blow with perfect accuracy, and the full force of the blow was concentrated on a narrow pick, so that it cut a much narrower groove than the collier could possibly do, and was thus enabled to undercut a much greater length of coal in the same time ready to be benched down: the first pick cut a groove of only 2 inches width, the second $1\frac{5}{8}$ inch, and the third a groove only $1\frac{1}{4}$ inch wide. The average width of the groove from the face to the innermost extremity was therefore not so much as 2 inches, and it was only this very small portion of coal that had to be cut out in slack by the machine, in place of the large excavation required to be made by the collier for undergoing the coal to the same distance in. The machine was thus in fact not a coal crushing, but literally a coal *cutting* machine.

Mr. **Sampson Lloyd** enquired how many of the machines were now at work, and whether in any instance where they had been introduced they had afterwards been discarded.

Mr. F. **Levick** said there were only two of the machines yet at work in the present form, but a number more were in progress; and there were as many as twenty or thirty holing machines in use upon the previous construction, before the improvement of the rotating headstock had been added, for enabling the pick to work at all inclinations. No one who had once tried the machine had discarded it, and all who had already got it at work intended to employ it more extensively.

The **Chairman** suggested that, if one of the machines were shown at work in the South Staffordshire district, that would be a satisfactory mode of practically testing its capabilities and advantages.

Mr. F. **Levick** said one of the machines had been shown at work above ground in Manchester, and had been tried upon a block of Bath stone for the purpose, from the bottom of which it cut out a groove of 2 inches width with great facility, quite smooth and clean.

Mr. F. **Smith** said that at the Earl of Dudley's collieries he should be happy to arrange for affording every facility for a thorough practical trial of the coal cutting machine.

The **Chairman** proposed a vote of thanks to Mr. Levick for his paper, which was passed.

The following paper, communicated through Mr. Edward Jones of Wednesbury, was then read:—

ON PUDDLING IRON BY MACHINERY.

BY MR. HENRY BENNETT, OF WOMBRIDGE IRON WORKS.

In the manufacture of wrought iron from the crude pig iron, the purifying of the metal by the process of Puddling involves very heavy and long continuous hand labour; since the metal, after being melted in the puddling furnace, has to be continuously stirred for a considerable time whilst boiling, in order to expose it thoroughly to the action of the current of air passing through the furnace, so as to effect the chemical changes required for the separation and removal of the impurities originally combined with the iron. The metal has then to be balled up into separate masses of about ¾ cwt. each for the shingling hammer; and the whole process extends over about an hour from the time of melting the pig iron for each heat, of which six are worked in the day.

The application of machinery to puddling has long been felt to be very desirable, on account of the laborious nature of the process, owing to the continuous heavy work required and the great heat to which the men are exposed; and the simple mechanical character of the greater portion of the process, which consists in merely a continuous uniform stirring of the material, renders it very suitable in that respect for the application of machinery. But the high temperature of the furnace and the necessity for not interfering with the current of air passing through it, which has to be regulated and changed as the process advances, cause great practical difficulties in successfully carrying out the application of machinery in place of hand labour.

Many attempts have been made to accomplish puddling by machinery. A rotary furnace has been tried, having the portion containing the melted iron made to revolve by machinery horizontally upon a vertical axis, with a scraper placed across it for stirring the metal as it revolved, the object being to effect the entire operation by machinery; but the practical difficulties in keeping such a machine at work and obtaining the proper result in the process were found too great to be surmounted. Various attempts have also been made to produce an action similar to that of the hand puddling process, by means of machinery more or less complicated; but it is important that any apparatus for the purpose should be simple in construction, and not liable to get out of order under the rough usage of the men by whom it has to be worked.

In the plan to be described in the present paper, the object of the writer has been to adhere as closely as possible to the ordinary course of hand puddling, and to employ machinery simply to aid the puddler by relieving him of the most laborious part of the work, namely the stirring or working of the metal in the puddling furnace. At the same time the objects aimed at have been, by a more rapid and uninterrupted process of stirring the metal, to shorten the time of the puddling, thereby economising fuel; to improve the quality of the iron, by rendering the process more uniform and perfect than with hand labour; and to increase the yield of the furnace, by working larger charges than could be both puddled and balled up at one heat by hand labour alone.

The apparatus is shown in Figs. 1 to 4, Plates 87 to 90, which represent it as applied to a double puddling furnace worked from both sides. Fig. 1 is a transverse section of the furnace, Fig. 2 a plan of the top of the furnace showing the machinery, Fig. 3 a longitudinal section of the furnace, and Fig. 4 a sectional plan showing the area worked over by the machine.

The ordinary puddling tool or "rabble" A A, Fig. 1, is worked backwards and forwards in the puddling furnace by the vertical arm B B outside the furnace, to which it is connected by a notch in the handle of the rabble, dropped loosely upon a pin at the bottom of the working arm. This arm is cottered at top into a horizontal square slide bar C C overhead, sliding longitudinally through two guide sockets D and E, and worked by the connecting rod F F from the main bar G G, which is a long T iron bar extending horizontally across a whole row of puddling furnaces, being carried by rollers I I in the frame fixed upon each furnace; and a longitudinal reciprocating motion is given to it by a crank at one end driven by engine power. The guide frame or sector carrying the guide sockets D and E of the sliding bar C is centred on a vertical pin immediately over the door of the puddling furnace, and the outer end is moved transversely from side to side with a slow reciprocating traverse along the guiding quadrant H, Fig. 2, by means of the connecting rod J from the crank K, which is driven through a worm wheel and screw L by the horizontal shaft M M extending over the furnaces alongside the reciprocating bar G.

The main bar G, Fig. 1, works at a speed of about fifty strokes per minute, and has a length of stroke of 2 ft. 10 ins., carrying the rabble with the same length of stroke across the floor of the furnace, as shown by the two extreme positions in the transverse section, Fig. 1, and the sectional plan, Fig. 4. The transverse motion given by the crank K, which makes one revolution for every seventy strokes of the rabble, causes the direction of each stroke to change gradually between the two extremes of the guiding quadrant H, Fig. 2; so that the end of the tool, instead of moving backwards and forwards always in the same line, is worked successively over every portion of the floor of the furnace within the range marked by the dotted lines on the plan, Fig. 4, in lines radiating from the working hole in the door of the furnace, corresponding exactly to the action in hand puddling. In the double furnace, with a door on each side, the two traversing cranks K K are set at right angles to each other, so that the two rabbles are always working in different parts of the furnace. The whole of the machinery is kept clear above the furnace, outside and completely protected from the heat, and quite out of the way of the men; nothing being exposed to the heat except the rabble or puddling tool, the same as in hand puddling.

The double furnace shown in the drawings is exactly the same in construction in all respects as the ordinary single puddling furnaces, except that it is made with a working door at each side, and is one foot wider inside.

When the charge of pig iron is melted and ready for the commencement of the process of puddling, the apparatus is put into action by simply dropping the notch in the handle of the rabble A, Fig. 1, on to the pin in the working arm B, which is kept continuously in motion by the horizontal reciprocating bar G working overhead. The puddler changes his tool from time to time as it becomes heated, by simply lifting the notch in the handle off the pin in the working arm, and replacing the tool with a fresh one, without stopping the machine; and when the iron begins to thicken, he takes the opportunity of each change of tool to make a few strokes by hand, in order to collect the metal from the extreme sides of the furnace into the centre, which is found to ensure the whole charge being uniformly worked. The usual time of working with the machine is about 25 minutes with ordinary forge pig iron, the tool being changed five or six times; but with grey iron the time of working is much prolonged. In the latter case the machine is especially serviceable, since the iron keeps in a fluid state much longer, and requires consequently so much more working; which causes the labour to be so much more severe in the case of hand puddling that there is great difficulty in getting the men to work any iron that is very grey. With the machine however this causes no increase of labour to the men, and only increases the time of the process.

When the iron begins to thicken, or as it is termed is "coming to nature," the machinery is disconnected without stopping it, by simply knocking out the cotter that fixes the upper end of the vertical working arm B, Fig. 1; the arm then drops out, leaving the furnace door entirely clear for the puddler to ball up the iron, which is done exactly in the same manner as in ordinary puddling furnaces, without the man being in any way inconvenienced by the machinery continuing at work overhead.

The general objects aimed at in this puddling machine have been simplicity of construction and action, and small cost both in construction and repair. The machine has nothing in it liable to get out of order, and possesses great durability in the working parts.

Also the object has been to improve the quality of the iron produced, by its being more thoroughly and uniformly worked than is done by hand labour. When the metal is in the boiling state, it is known that the more work is put into it the better is the quality of the iron produced; and this work is necessarily better done by the machine than it can be by hand, since the speed of working with the machine is one half greater, and the working is kept up uninterruptedly, without any intervals for rest such as in hand labour, during which the metal would remain stationary in the furnace.

The machine is applied to ordinary single puddling furnaces by employing simply one half of the apparatus shown in the drawings, without any alteration being required in the furnace, the frame of the apparatus being merely attached to the top of the furnace. The double furnace shown in the drawings is preferable however, as it effects a great economy in the consumption of fuel, as compared with a single furnace; and puddles double the quantity of iron in the same time. With the single furnaces at the writer's works, and charges of 5 cwts., the consumption of coal is 28 cwts. per ton of puddled bar made; but with the double furnace and charges of 10 cwts., the consumption of coal is only 17 cwts. per ton of puddled bar, being a reduction of 39 per cent. The number of heats or charges worked in the single furnace is six heats of 5 cwts. each, and in the double furnace five heats of 10 cwts. each, per turn of from 9 to 10 hours. In working the double furnace it is found best to have one puddler only and two underhands, to avoid the division of responsibility that would arise in the case of two puddlers working the same charge of iron.

The yield of iron in working 5 cwts. charges in the single furnaces is 18 cwts. 2 qrs. 21 lbs. per ton of pig, or 93½ per cent.; and with the double furnace working 10 cwts. charges the yield is 18 cwts. 2 qrs. 9 lbs. per ton of pig, or 93 per cent.

The **Chairman** regretted that Mr. Bennett was unexpectedly prevented from attending the meeting; but the manager of his works, Mr. Fisher, was present, and would be happy to afford any further information that was desired respecting the puddling machine. He understood that the machine had been tried at the Old Park Iron Works, Wednesbury, and enquired what had been the experience of its working there.

Mr. P. **Barker** replied that they had had two of the puddling machines described in the paper at work at the Old Park Iron Works during the past two months, with very satisfactory results. The machines worked 5 cwts. of iron at each charge, instead of 4 cwts. previously worked by hand, and with the same amount of fuel; they had been worked only in the day at present, as there had been no occasion yet to work them constantly both night and day. As far as the work done was concerned, the present machine had been found very good indeed; but he thought the construction was rather complicated, and hardly strong enough to stand the rough usage that any machinery must be expected to meet with in connection with the operation of puddling. He had recently seen also a puddling machine at Mr. Eastwood's works at Derby, which worked an ordinary rabble in a somewhat similar manner; and thought that machine appeared to have a superiority in respect of strength and durability.

Mr. **Henry Maudslay** observed that if the machine described in the paper were found too light for durability in any parts, it might easily be made stronger to any extent desired. It appeared to him to be a well designed machine for the purpose, with a simple and direct action for working the rabble equally and regularly over all parts of the furnace. He enquired what had been found to be the durability of the machines at the Wombridge Iron Works.

Mr. W. **Fisher** replied that the puddling machines had now been at work constantly during the day for the last six months at the Wombridge Iron Works, and continued to work as well now as they did when they were first started; and there had been no occasion to repair any of the working parts since then, as the machines had been found very simple and strong. A man went round twice a day, and put a little oil on morning and evening; and they could be worked night and day when desired. At first there had been a little difficulty in introducing the machine; but now the men felt its advantage, and were anxious to have it employed on night work also.

The six months' experience of the working of the machine had shown that 5 cwts. of iron were puddled by it in the time that a man would take to puddle 4 cwts.; and it was also found that the machine made a great improvement in the quality of the iron. This was accounted for by the fact that, while in hand puddling there was the liability of the underhands frequently neglecting their work, the machine went steadily on, working the tool constantly to and fro in the furnace without any intermission, and kept the iron well stirred during the whole time that the work was required to be put into it. The consequence was that very seldom was a bit of raw iron seen from the puddling furnaces worked by the machine; and the puddled bars were very seldom found to break off short in the rolling, unless the iron were a little too hot. In the heavy operation of puddling it was impossible for any puddler to stand up to his work as the machine did, since the machine never tired, but kept on steadily at the work without rest, and at a quicker rate of working than in hand puddling. By using the machine to do the heavy part of the work, it was only required for the puddler occasionally to disengage the tool and draw the iron from the sides of the furnace into the centre, leaving the machine during the rest of the time to perform its work alone. When the iron was ready for balling up, the puddler came fresh to the work; and from the men being relieved of the severest part of the labour, the furnaces worked by the machine turned out about 5 cwts. at each heat and six heats during the day, with the same quantity of fuel as was used for the ordinary heats of only 4 cwts. in hand puddling with six heats per day. The average result of the day's work with the machine was about 28¾ cwts. of puddled iron from 30 cwts. of pig iron, as compared with about 22¼ cwts. of puddled iron from 24 cwts. of pig iron by hand puddling. The improvements effected by the machine were therefore that it produced a better quality of iron with a decreased consumption of fuel, and turned out more iron in the same time. The machine did not interfere with the wages of the underhands, as they had to be employed the same as without the machine; whilst the puddler's wages were increased by his being enabled to turn out more iron in the same time.

The Chairman enquired how many of the puddling machines described in the paper there were at work, and what was the longest time that any one had been in use.

Mr. W. Fisher replied that they had six of the machines now at work at the Wombridge Iron Works, and there were also two at the Old Park Iron Works, Wednesbury, one at the Horsehay Iron Works near Wellington, three or four in the North of England, and about a dozen in South Wales. The longest had now been at work nearly twelve months. In the first machine the traversing motion of the guiding quadrant was given by a rack and pinion reversed by a mangle motion; but this was now replaced by the crank motion shown in the drawings, which was a simpler arrangement.

Mr. F. Smith enquired whether it was necessary for the puddling furnaces to be placed in any particular position, in order that the machines might be employed to the best advantage. At the Earl of Dudley's new ironworks at Round Oak, the puddling furnaces were placed in a semicircle, which was considered the most eligible arrangement: and he did not see how the mode of working the machines by means of a long bar driven by a crank, as described in the paper, could be made applicable in that case.

Mr. W. Fisher replied that the best arrangement as regarded the working of the puddling machines was to place the furnaces back to back in pairs, and then the single long bar running from end to end of the forge would work as many pairs of furnaces as were placed under it.

Mr. Sampson Lloyd observed that in regard to the circular arrangement of the puddling furnaces the adoption of small donkey engines for working each machine or each pair of machines would completely obviate all difficulty, and would allow of placing the puddling machines in any positions that might be desired, while the difference of cost would be comparatively little.

Mr. W. **Mathews** remarked that there were three essential points to be considered in connection with the application of machinery to puddling: namely, the quality of the iron produced, the quantity of the yield, and the saving of fuel; and he enquired whether the use of the puddling machine materially affected the quality of the puddled bar produced, under the same conditions that applied to ordinary hand puddling, with a reasonable proportion of grey iron supplied to the puddling furnace for each charge.

Mr. W. **Fisher** replied that, whilst with hand puddling the puddled bar broke very short and the general quality was indifferent, the iron puddled by the machine was much superior in quality, strong and fibrous. The yield was much greater in puddling by the machine, as there was less liability of the pig iron being burnt in the furnace for want of regular stirring; and in respect to saving of fuel, a heat of grey iron was now puddled by the machine with the same amount of fuel that was required in hand puddling for a heat of only common forge pig.

Mr. W. **Mathews** remarked that if this were the case, and if there were no inconvenience in making the machine as strong as might be found necessary to ensure its durability, there appeared no doubt that very important advantages would result from the substitution of the machine in place of hand puddling, particularly in rendering the masters independent to a great extent of puddlers. The application of mechanical means to puddling had been attended with so many difficulties that it had not been practically accomplished hitherto, and the puddlers had thus been virtually able to make their own terms with their employers; and how the latter were to get out of this difficulty was a question of great importance at the present time. The extension of commercial operations had far outstripped the increase of population, and he therefore did not anticipate that the introduction of puddling machines would in any material degree deprive the puddlers of employment; since, notwithstanding the extent to which machinery had been already substituted for manual labour in all branches of industry, the demand for labour was as a rule constantly in excess of the supply. He accordingly looked with a great deal of interest on the puddling machine, as tending to advance the social condition of the men as well as to solve a great difficulty for the masters, and should do all he could to aid its introduction and adoption in general use: and he intended to take an early opportunity of seeing it in operation at the works where it was already employed.

Mr. G. **Beard** thought the mode of working the rabble in the puddling machine shown in the drawings was by too rigid a connection: and he enquired whether any difficulty had been met with on that account when the puddler happened to put rather too much fettling into the furnace, from the tool disturbing the fettling. The successful management of the fettling was a very important element in the working of puddling furnaces, that the iron might not be put in the furnace before the fettling was properly melted, and that the fettling might not be disturbed by the rabble in working; since if any of the fettling got into the iron, it could never be separated from it. There would also be a risk he thought of a rigid tool raking the iron over the fore plate and wasting the metal, which would not be the case with a more elastic tool and a man guiding it. At the Regent Iron Works, Bilston, he had three of Griffiths' puddling machines at work, and had at first found a difficulty owing to the rigidity of the arm working the tool, which caused the tool to pull out the fettling; but this had now been overcome by using a lighter suspending hanger for working the tool, so that the tool travelled only the required length of stroke, and the elasticity of the hanger allowed it to spring a little at either end of the stroke whenever necessary; and the tool was moreover guided by a man during the whole time of working.

His own experience of the results of puddling by machinery was that it was a decided improvement in all respects. The first advantage gained was that the quality of the iron made was improved, by its being worked with much greater regularity than a man could work it, and it was much cleaner by the time it was ready for balling up. He had found the iron puddled by the machine was as good as that worked by hand when the pigs used with the machine were 3*s*. or 4*s*. per ton less in price than those used in hand puddling. Another advantage was that much larger quantities could be puddled by the machine and with a smaller quantity of coal: at his own works the quantity of iron worked by each of the three puddling machines was 6 cwts. per heat, and five heats per turn, and he saw no reason why the make should not be increased to 2 tons per turn from each furnace, by working larger heats. At present however the men got out the iron much better in working 6 cwts. heats than they would do with heavier charges. The rate of wages paid to the men was the same with the machines as in hand puddling.

Mr. W. **Fisher** explained that in the machine described in the paper the rabble had two nicks made in it at about 6 inches distance apart, either of which could be slipped over the pin of the arm working the rabble, according to the distance to which the tool was required to be worked in the furnace. On first starting a fresh heat after fettling the furnace, the tool was first worked at its shortest length by means of the inner nick, so as not to travel so far towards the back of the furnace; and afterwards it was changed to the other nick for working to its full distance in the furnace. There was no risk of the tool disturbing the fettling in working, as the rabble merely rested loosely with its weight upon the bottom of the furnace, just the same as in hand working. A great deal of responsibility rested upon the man attending to the machine, as regarded the proper condition of the fettling, and great care was necessary on the part of the foreman to see that this was properly looked after. The furnace should be well heated and the fettling melted and well knocked up before the charge was allowed to be put in; for if the fettling were simply thrown in and not properly broken up and melted, it was of course likely to get mixed with the iron in puddling; but when well knocked up in the first instance, while hot and soft, it was found to stand as well as if it had been laid on with a trowel.

In reference to the quantity of iron in the charges, they had worked 6 cwts. charges with the machine at the Wombridge Iron Works in the same time as 5 cwts., and in less time than the usual 4 cwts. heats puddled by hand labour; and he had no doubt 6 cwts. would ultimately be reached as the regular charge with the machines wherever they were employed. At first there had been a difficulty in getting the men to work more than five heats in the day, and they were allowed to remain at that; but when one man had succeeded in working six heats per day regularly, the others wanted to get as much out of their furnaces, and found they could readily do it; and six heats per day was now the regular make of each of the furnaces worked by the puddling machines. He should be happy to show the working of the machines at any time, as they were in regular work every day.

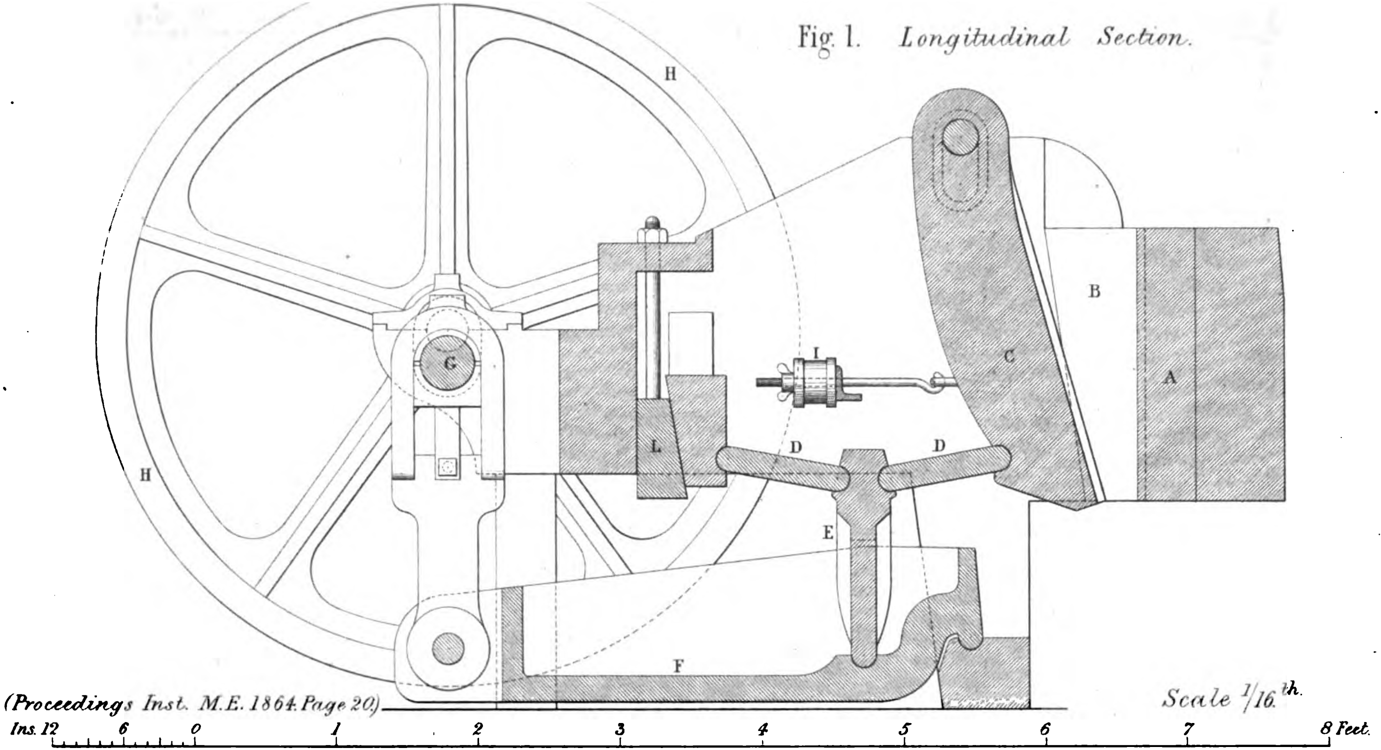
The Chairman proposed a vote of thanks to Mr. Bennett for his paper, which was passed.

The Meeting then terminated.

STONE BREAKING MACHINE.

Plate 1.

Fig. 1. *Longitudinal Section.*



(Proceedings Inst. M.E. 1864. Page 20.)

STONE BREAKING MACHINE.

Plate 2.

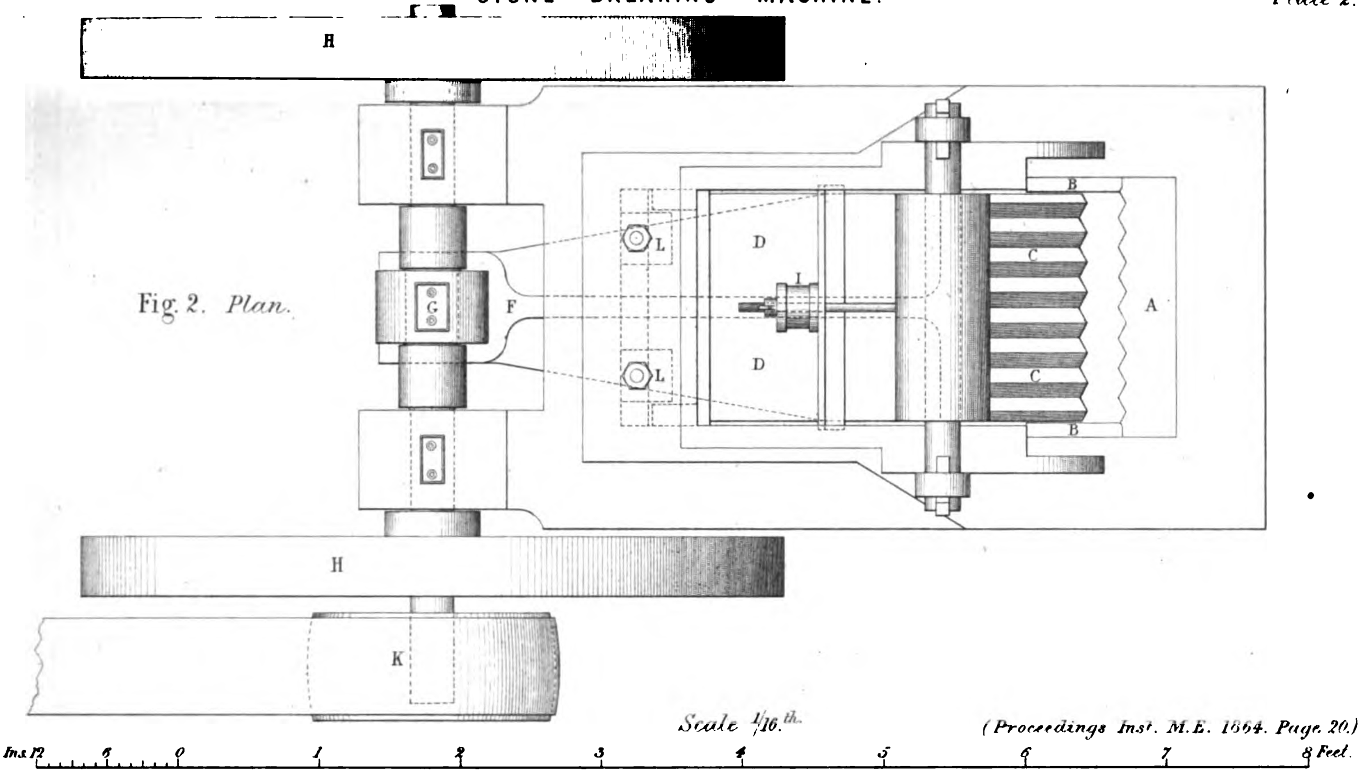
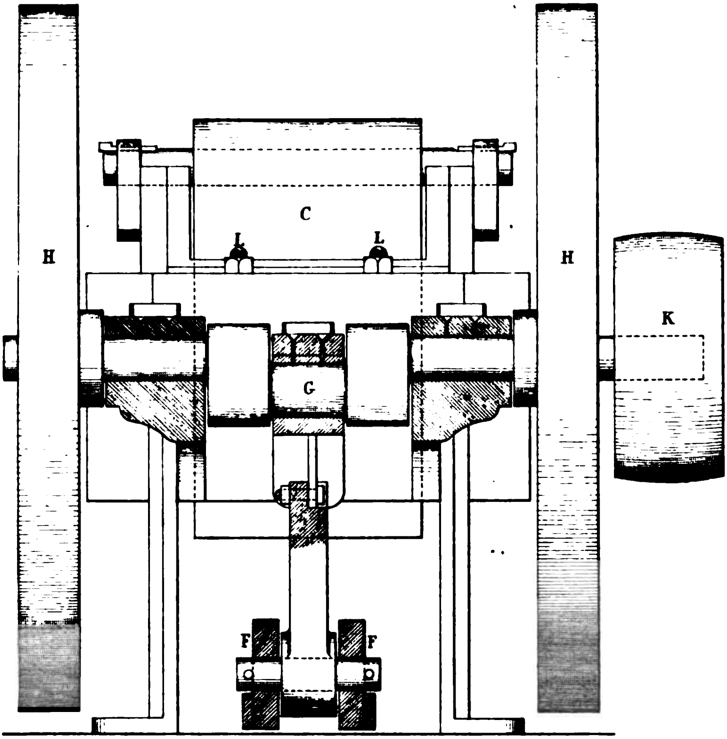


Fig. 2. Plan.

(Proceedings Inst. M.E. 1864. Page 20.)

STONE BREAKING MACHINE. *Plate 3.*

Fig. 3. *End Elevation.*



Thrust Bar of Toggle Joint.

Fig. 4.

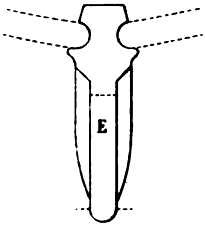


Fig. 5.

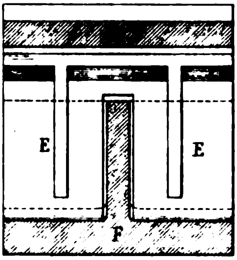
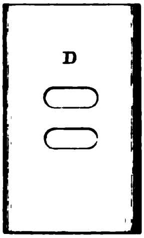


Fig. 6.
Strut Plate of Toggle Joint.



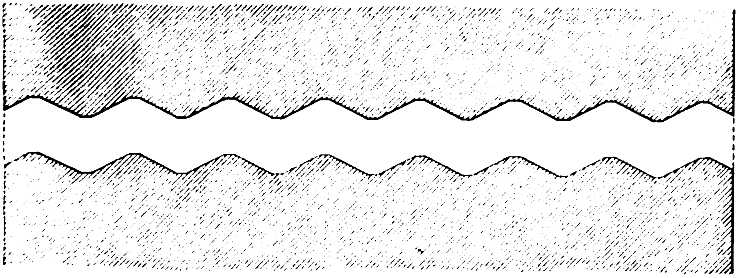
Scale 1/16th.

(Proceedings Inst. M. E. 1864. Page 20.)

STONE BREAKING MACHINE.

Plate 4.

Fig. 7. *Section of Jaws. Scale 1/5th.*



Full size Sections of Jaws.

Fig. 8.

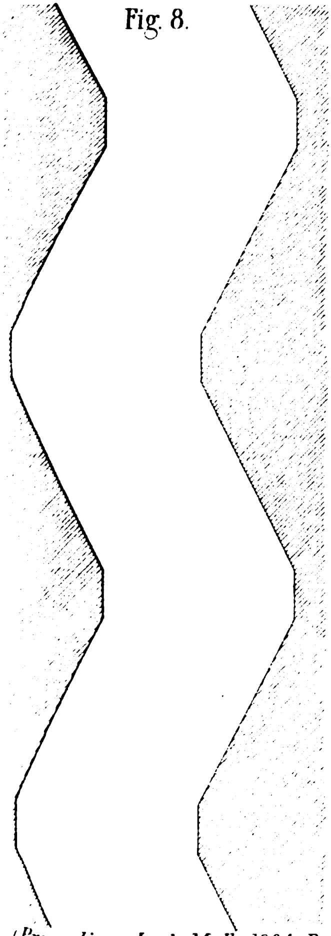
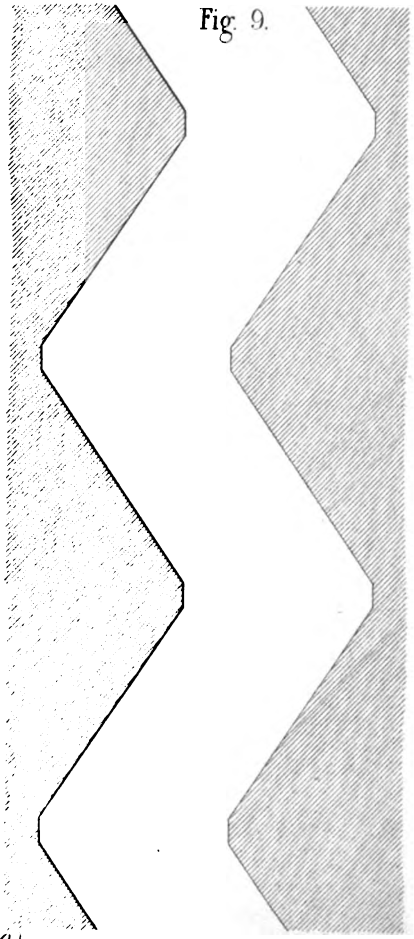


Fig. 9.



(Proceedings Inst. M. E. 1864. Page 20.)

HORIZONTAL V PUMP.

Fig. 1. *Transverse Section.*

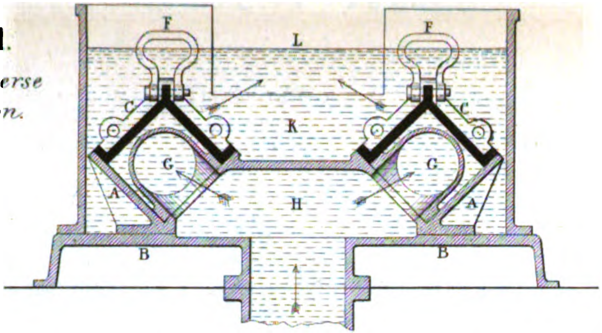
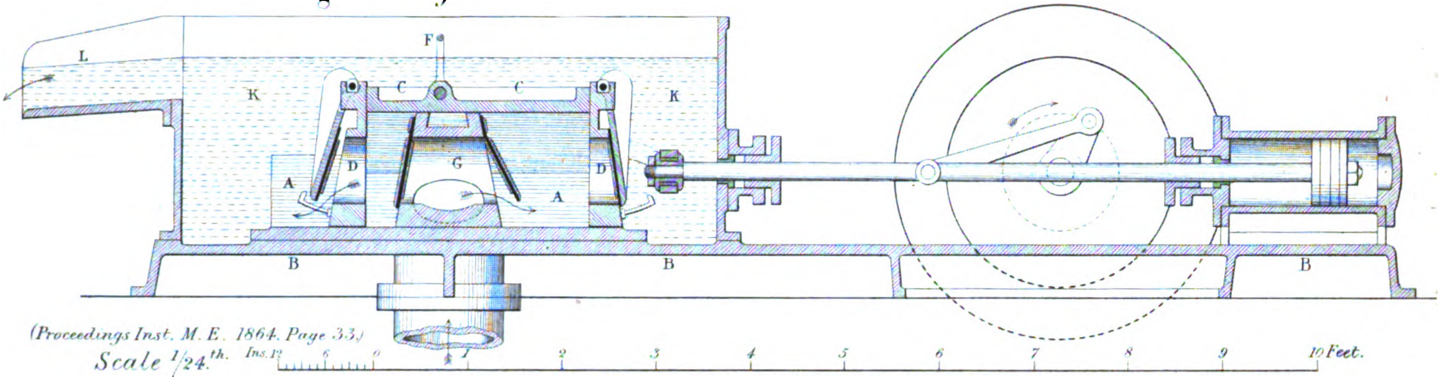


Fig. 2. *Longitudinal Section.*

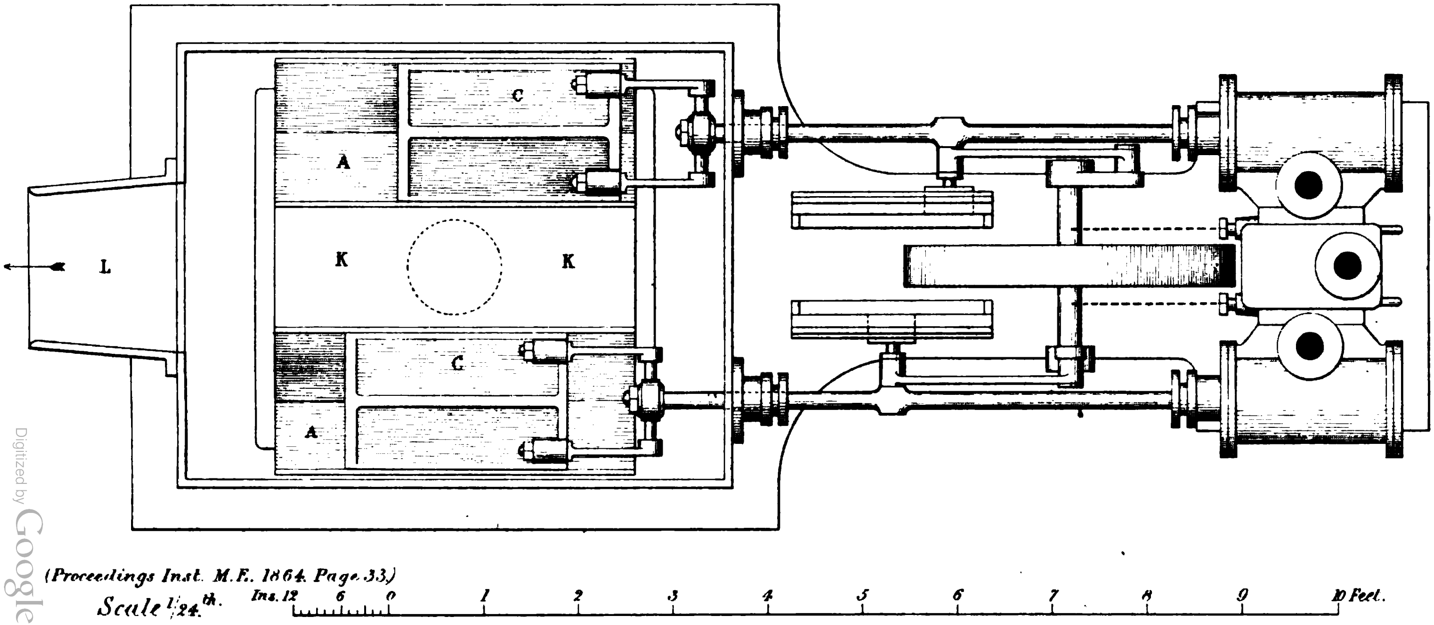


(Proceedings Inst. M. E. 1864. Page 33.)

Scale 1/24th.

HORIZONTAL V PUMP. *Plate 6.*

Fig. 3. *Plan.*



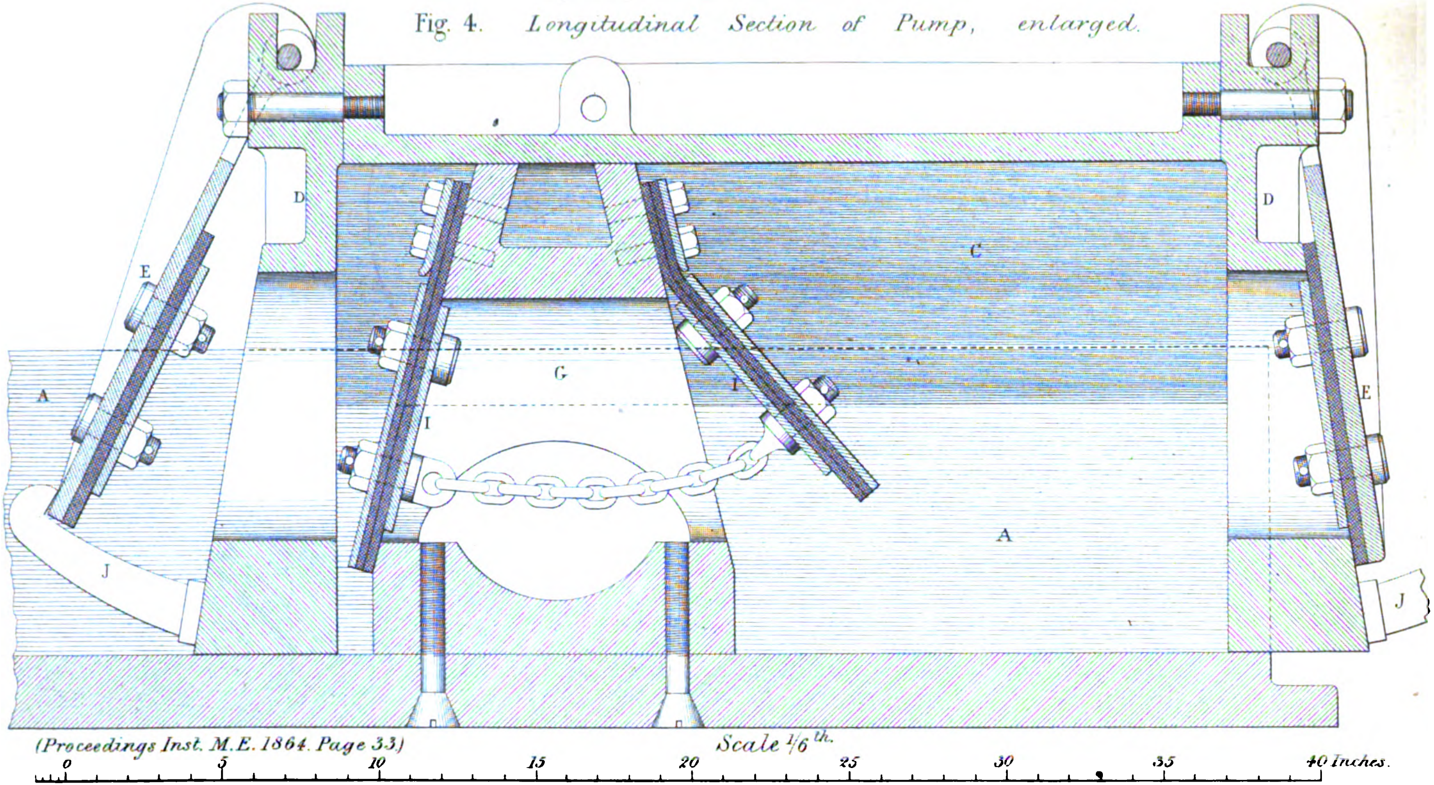
(Proceedings Inst. M.E. 1864. Page 33.)

Scale $1/24^{th}$.

Plate 7.

HORIZONTAL V PUMP.

Fig. 4. *Longitudinal Section of Pump, enlarged.*



(Proceedings Inst. M.E. 1864. Page 33)

HORIZONTAL V PUMP.

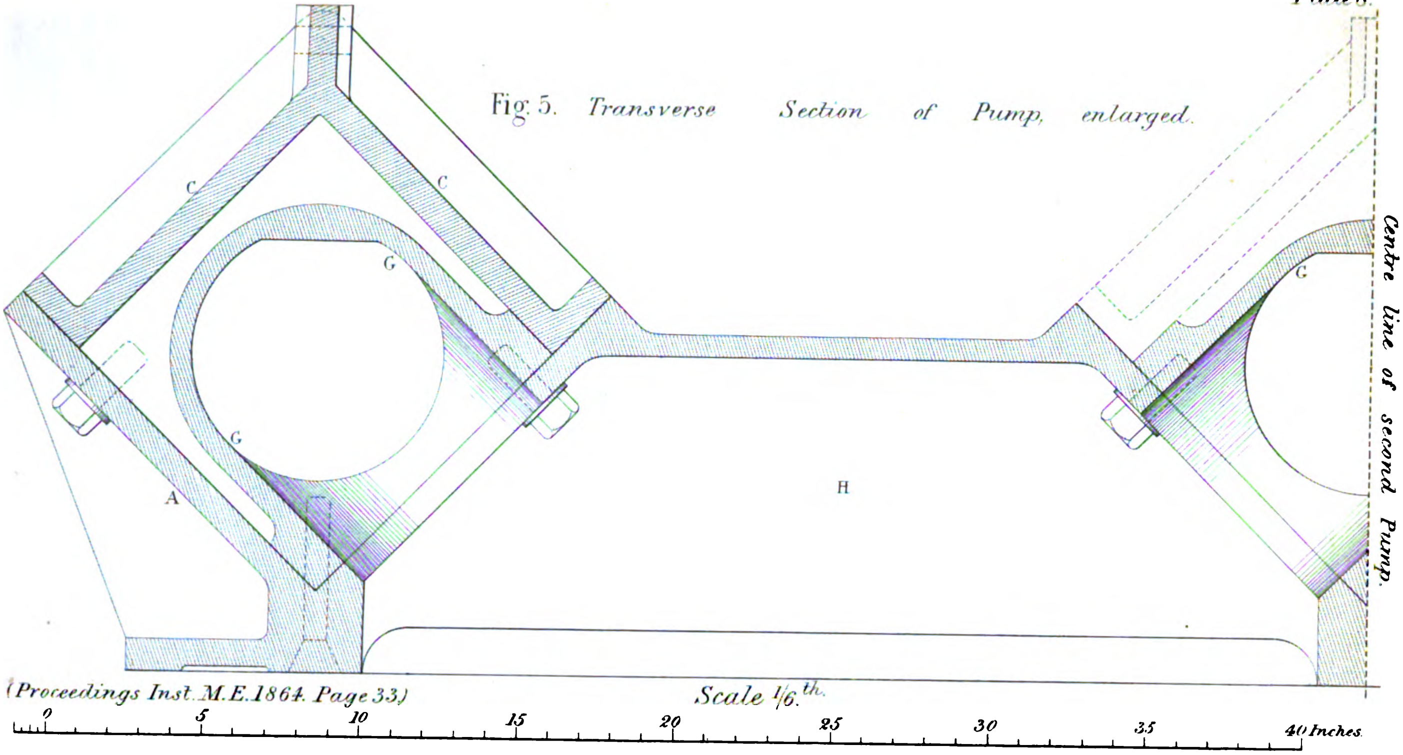


Fig. 5. Transverse Section of Pump, enlarged.

Scale 1/6th.

(Proceedings Inst. M.E. 1864. Page 33.)

OVERHEAD TRAVERSING CRANE. *Plate 9.*

Fig. 1. *Transverse Section of Engine Repairing Shop.*

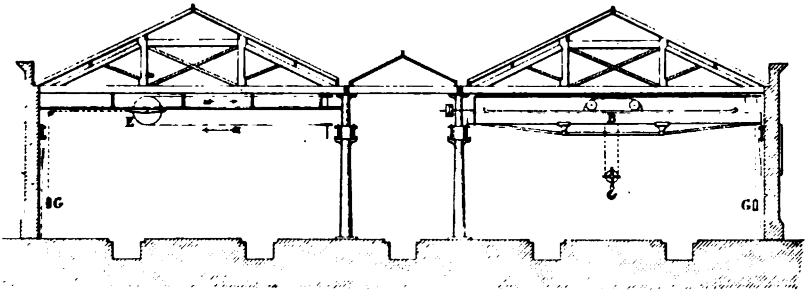
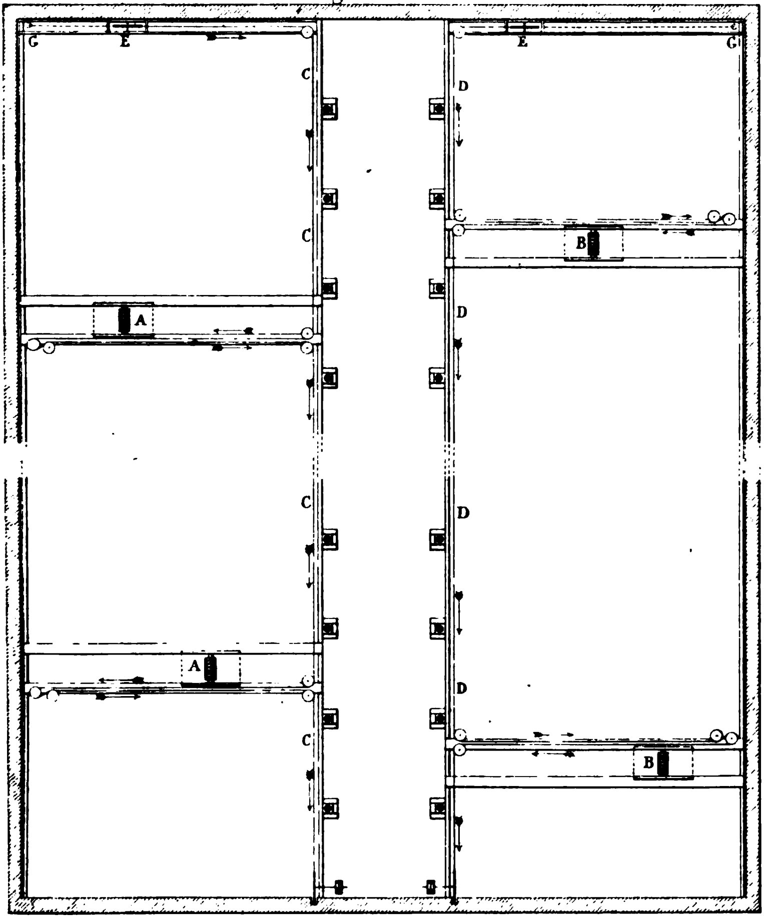


Fig. 2. *Plan.*



(Proceedings Inst. M.E. 1864. Page 44.)

Scale 1/320th.

0 5 10 20 30 40 50 60 70 80 90 100 Feet.

OVERHEAD TRAVERSING CRANE.

Plate. 10.

Fig. 3. *Side Elevation of Tightening Pulley for Driving Cord.*

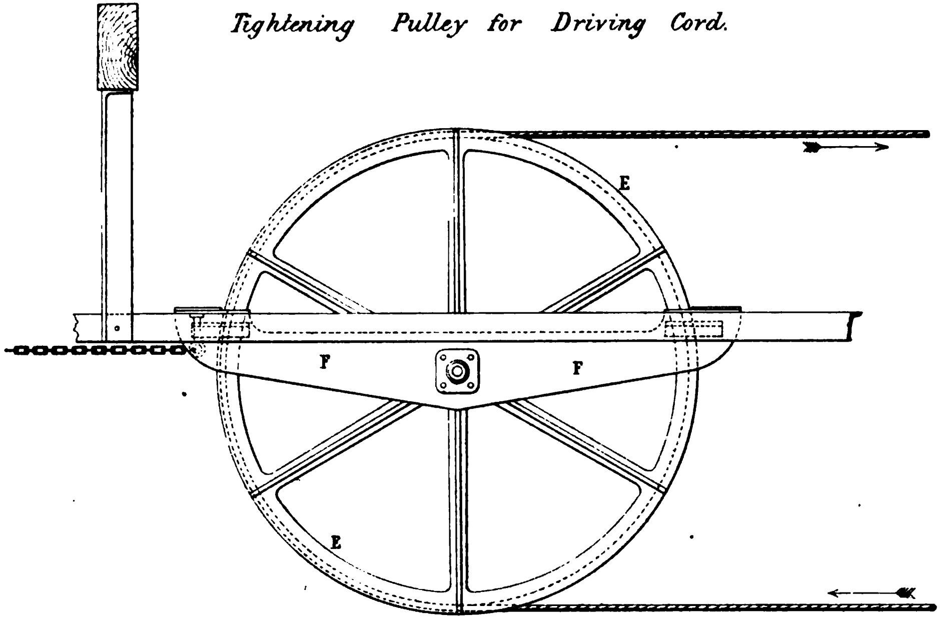
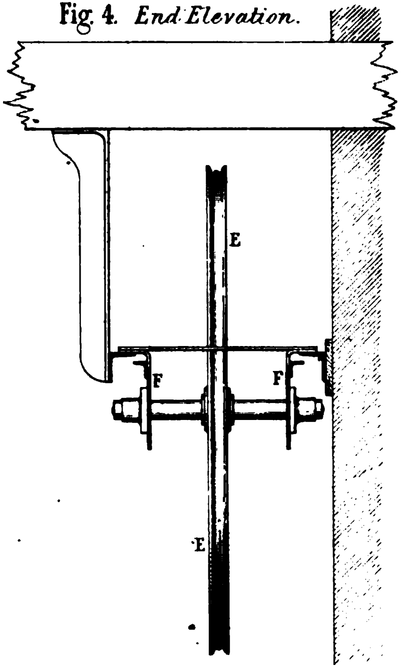


Fig. 4. *End Elevation.*



(Proceedings Inst. M. E. 1864. Page 44.)

Scale $1/20^{th}$ 10 5 0 10 20 30 40 50 60 *Inches.*

OVERHEAD TRAVERSING CRANE.

Plate 11.

Fig. 5. *Side Elevation of Traverser.*

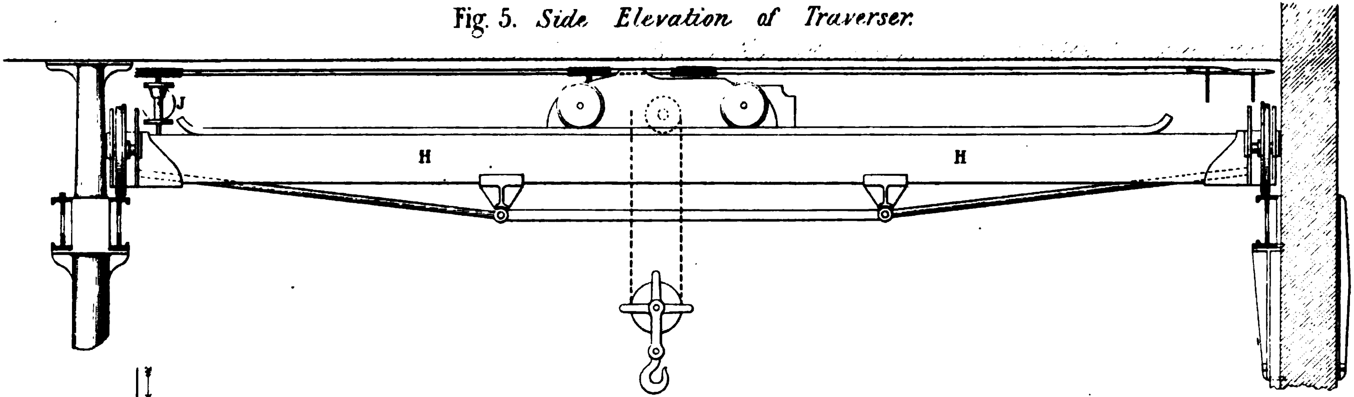
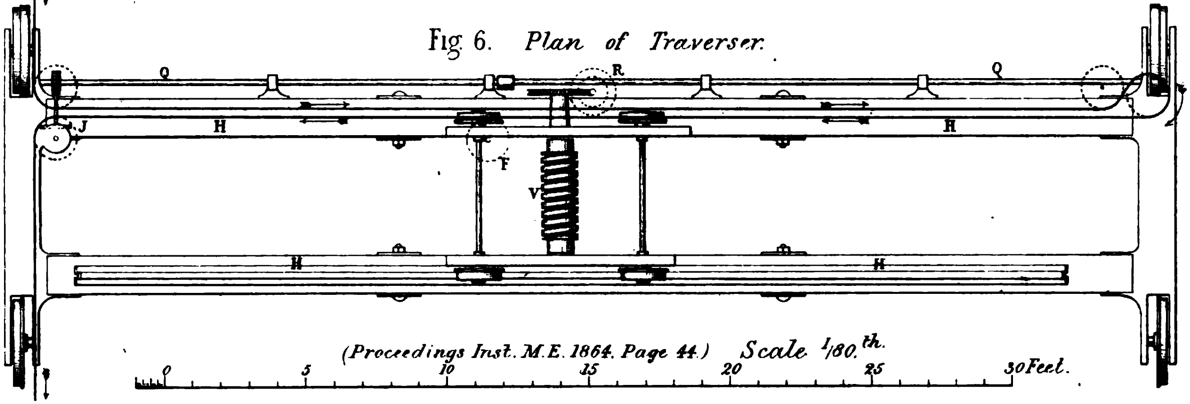


Fig 6. *Plan of Traverser.*



(Proceedings Inst. M.E. 1864. Page 44.) *Scale* 1/80th.

OVERHEAD TRAVERSING CRANE.

Plate 12.

Fig. 7. *Transverse Section at end.*

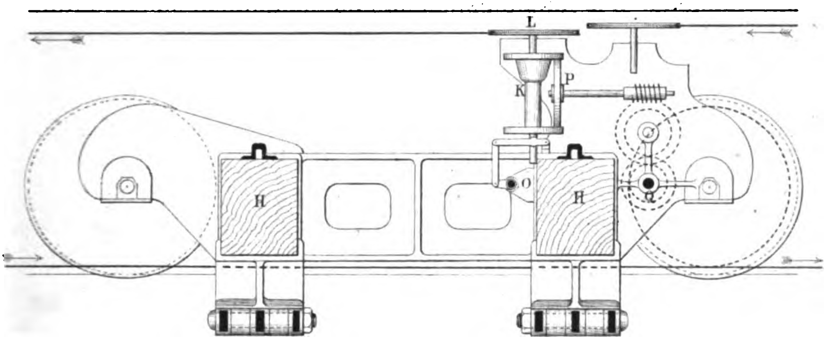


Fig. 8. *Transverse Section at centre.*

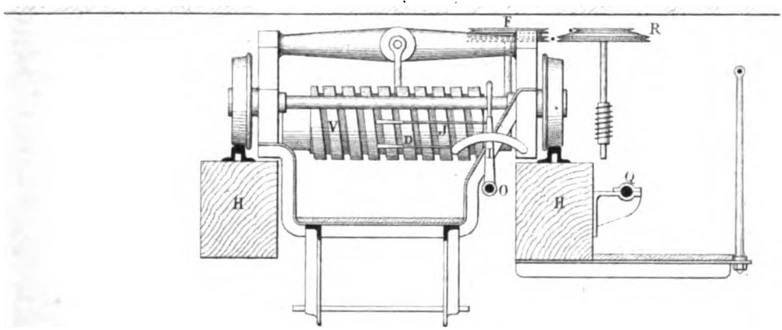
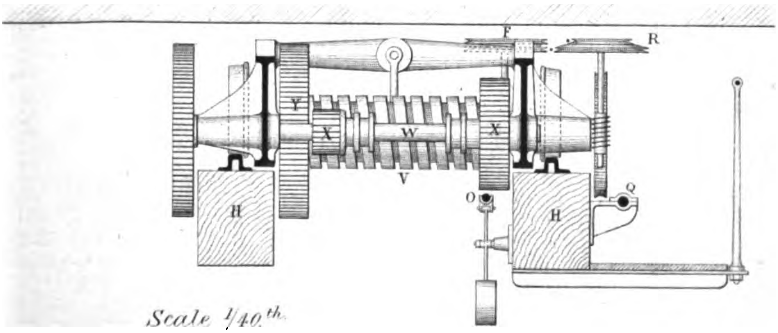


Fig. 9. *Transverse Section at centre.*



Scale 1/40th

0 1 2 3 4 5 6 7 8 9 10 11 12 Feet.

(Proceedings Inst. M.E. 1864. Page 44)

OVERHEAD TRAVERSING CRANE. *Plate 13.*

Fig. 10. *Longitudinal Section of Crab.*

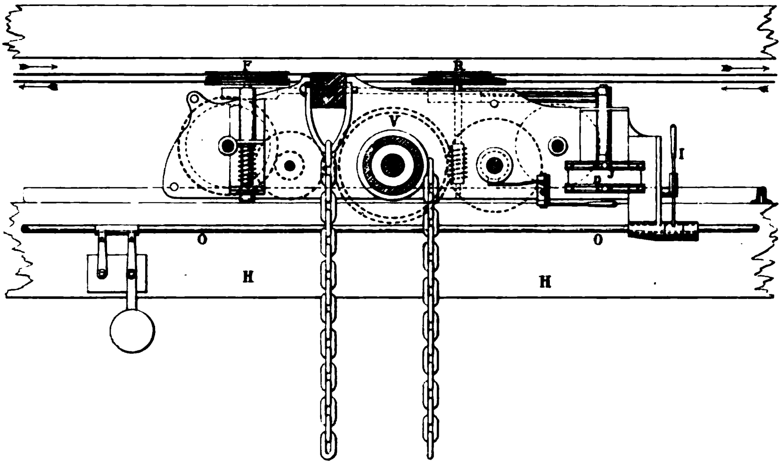


Fig. 11.

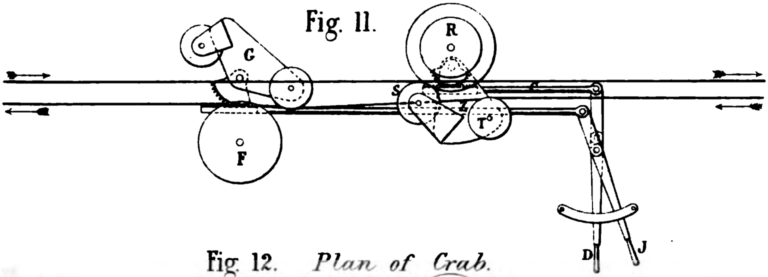
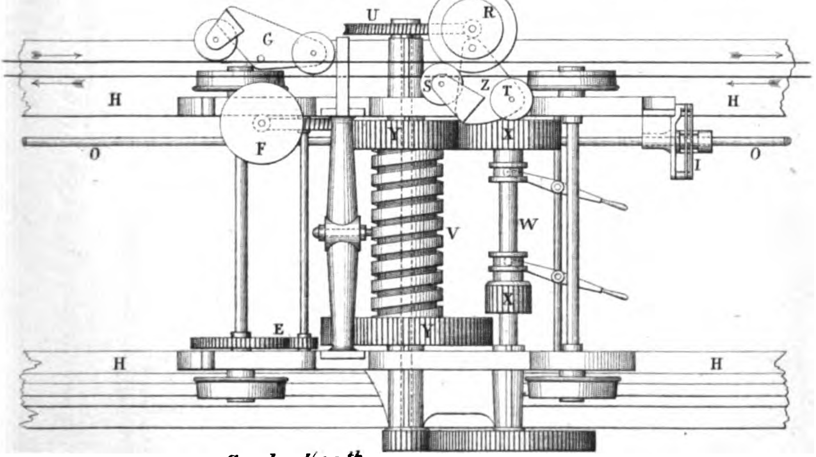


Fig. 12. *Plan of Crab.*



Scale 1/40th.

0 1 2 3 4 5 6 7 8 9 10 11 12 Feet.

(Proceedings Inst. M. E. 1864. Page 44.)

OVERHEAD TRAVERSING CRANE.

Plate 14.

Fig. 13. *Longitudinal Driving Gear.*

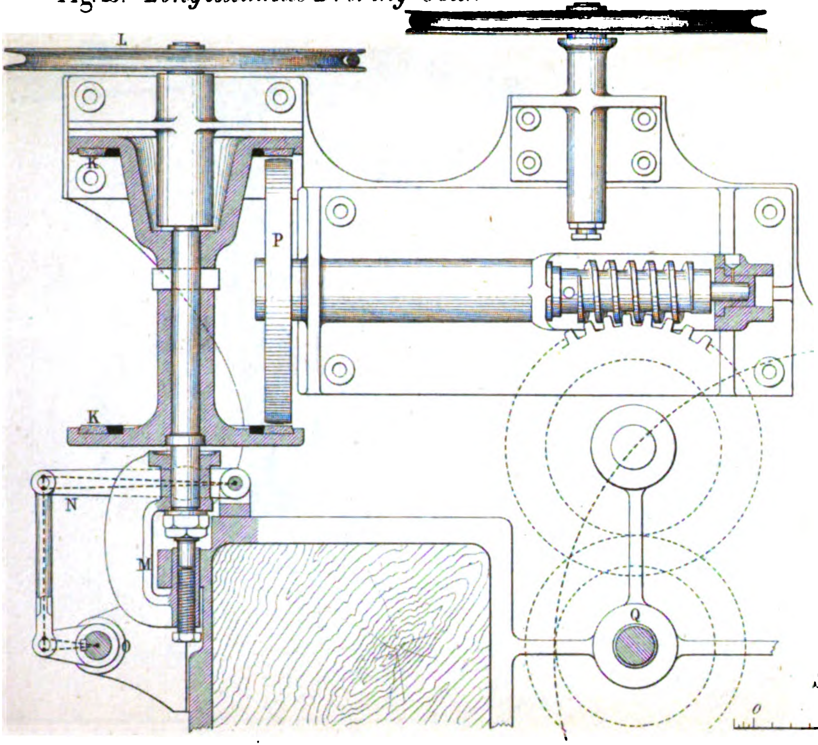


Fig. 14. *Lifting and Lowering Gear.*

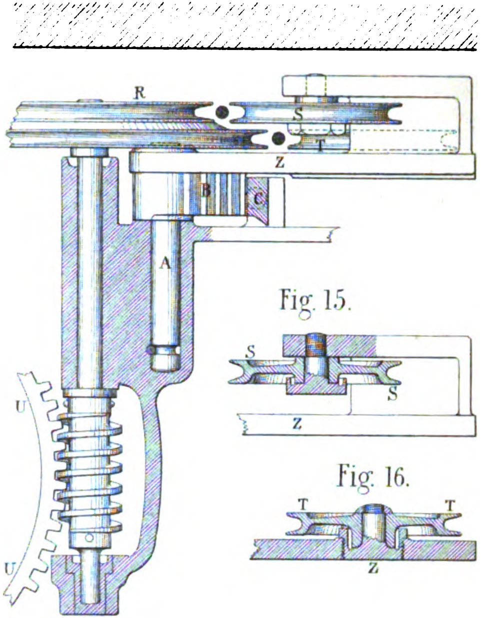


Fig. 15.

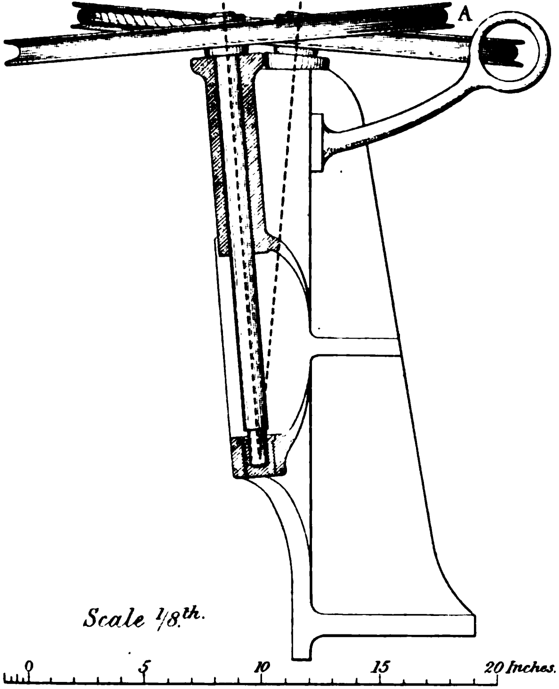
Fig. 16.

Scale 1/10th. *(Proceedings Inst. M. E. 1864. Page 44.)*

0 10 20 30 Inches.

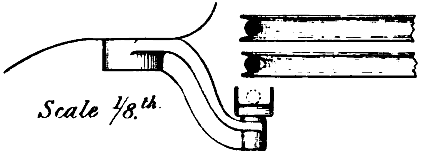
OVERHEAD TRAVERSING CRANE.

Fig. 17. *Returning Pulleys of Driving Cord.*



Scale 1/8th.

Fig. 18. *Slipper supporting Driving Cord.*



Scale 1/8th.

Fig. 19. *Longitudinal Section of Slipper.*

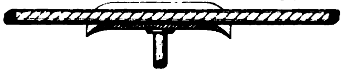
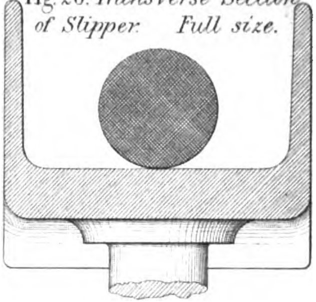


Fig. 20. *Transverse Section of Slipper. Full size.*



Full size Sections of Grooves of Pulleys.

Fig. 21. *Driving Pulleys.*

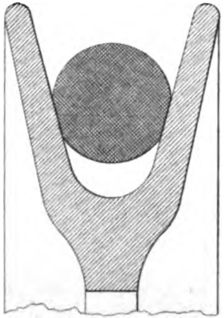


Fig. 22. *Guiding Pulleys.*

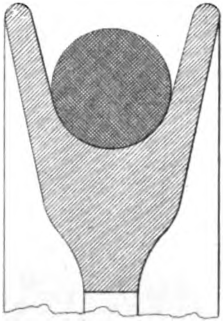
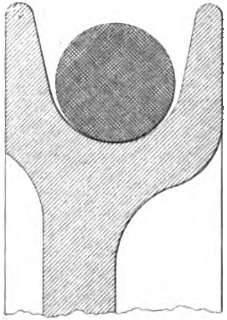


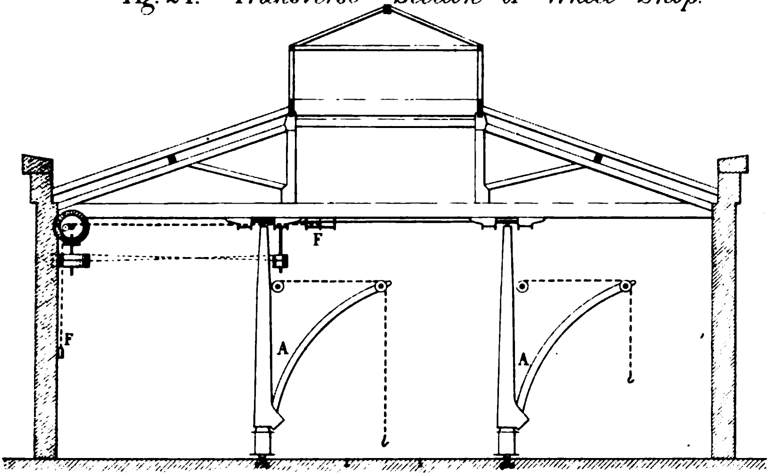
Fig. 23. *Presser Pulleys.*



(Proceedings Inst. M.E. 1864. Page 44.)

TRAVERSING JIB CRANE. *Plate 16.*

Fig. 24. *Transverse Section of Wheel Shop.*



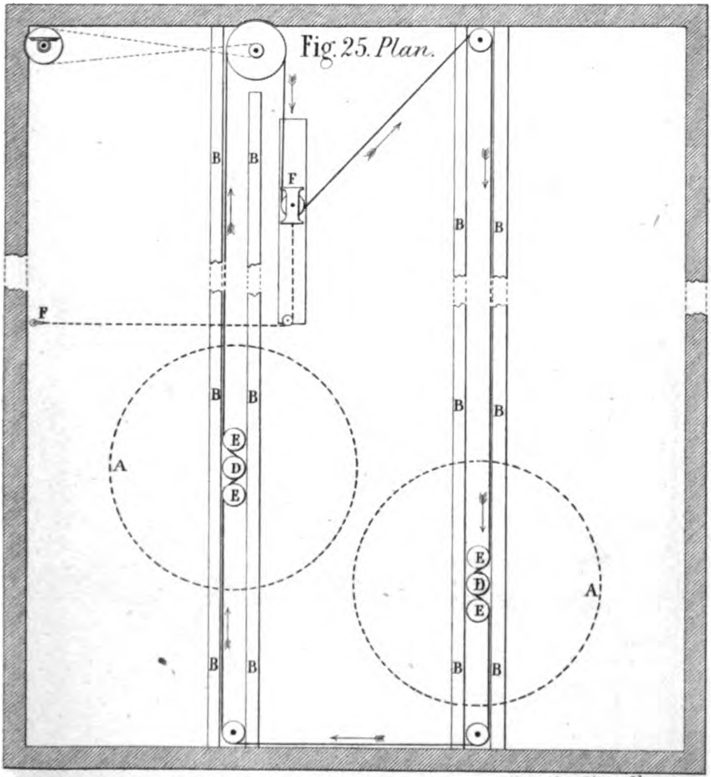


Fig. 25. *Plan.*

(Proceedings Inst. M.E. 1864. Page 44.)

Scale 1/160th.

10 5 0 10 20 30 40 Feet.

TRAVERSING JIB CRANE.

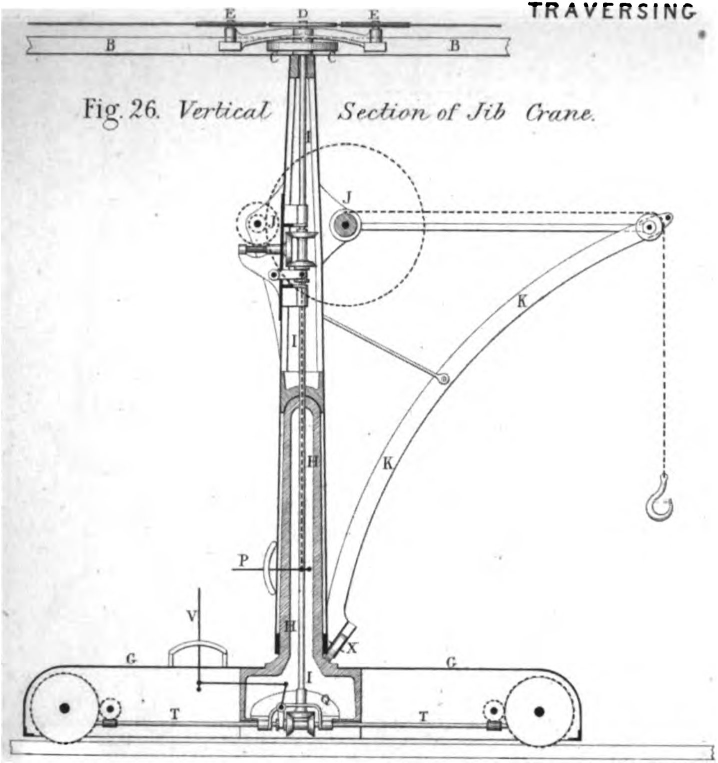


Fig. 26. Vertical Section of Jib Crane.

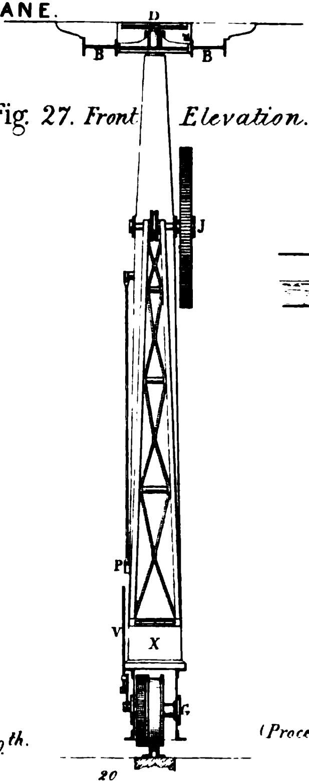


Fig. 27. Front Elevation.

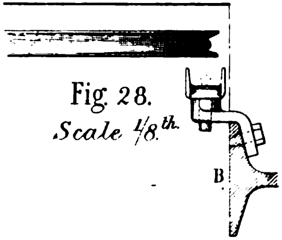


Fig. 28.
Scale 1/8th.

Scale 1/50th.

0 10 20 30 Feet.

(Proceedings Inst. M.E. 1864. Page 44.)

TRAVERSING JIB CRANE. *Plate 18.*

Fig. 29. *Elevation of Lifting and Lowering Gear.*

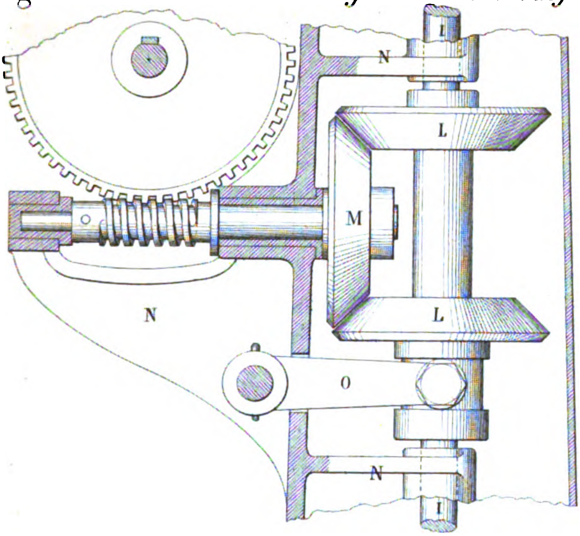


Fig. 30. *Sectional Plan.*

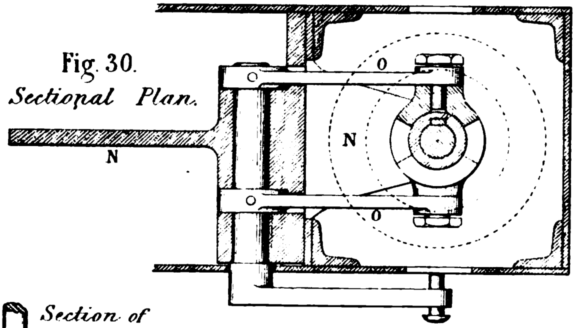


Fig. 32. *Section of Driving Cone of Traversing Gear.*

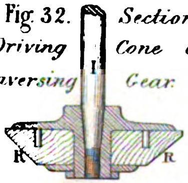
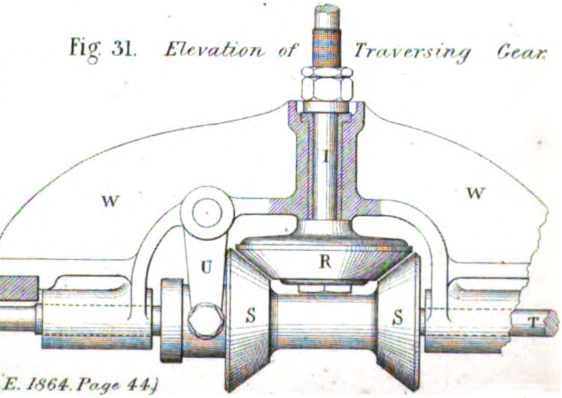


Fig. 31. *Elevation of Traversing Gear.*

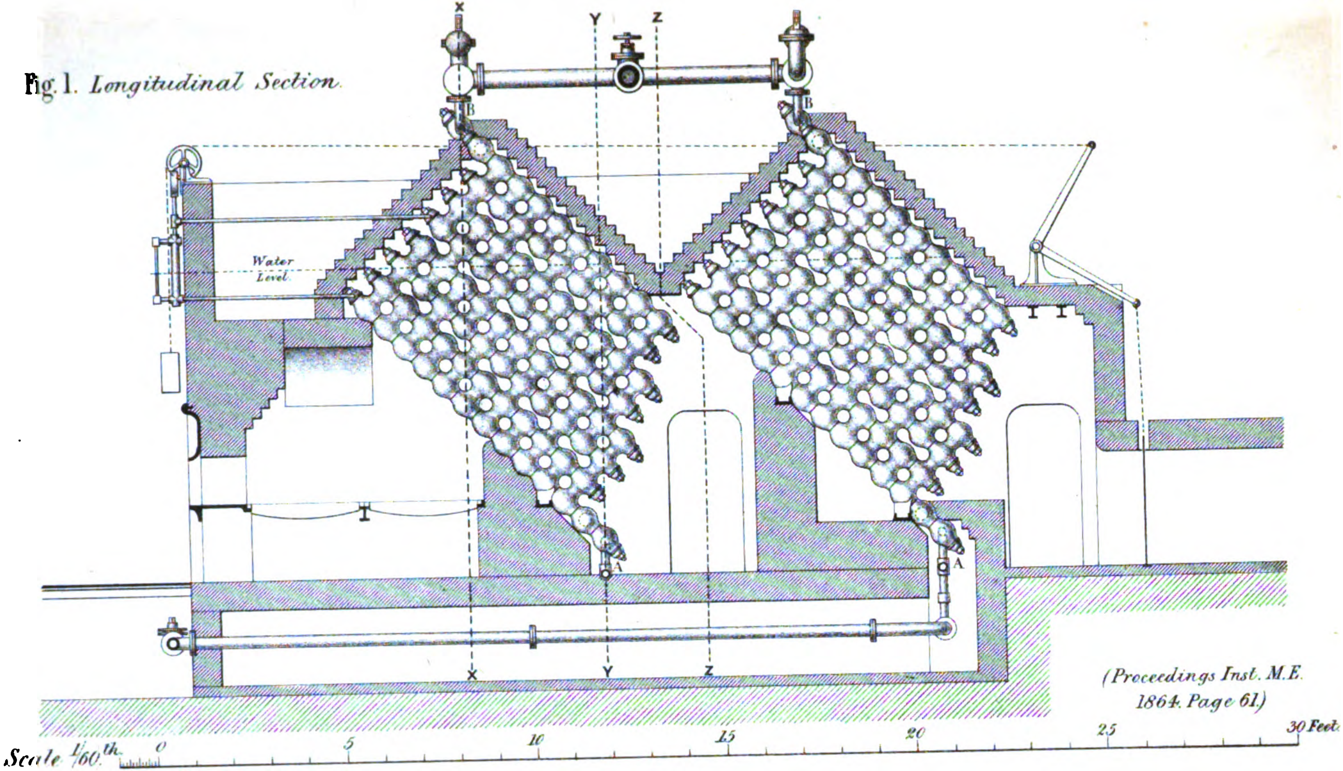


(Proceedings Inst. M. E. 1864. Page 44.)

Scale 1/8th. 0 10 20 *Inches.*

CAST IRON STEAM BOILER.

Fig. 1. Longitudinal Section.



(Proceedings Inst. M.E. 1864. Page 61.)

CAST IRON STEAM BOILER.

Fig. 2. *Front Elevation.*

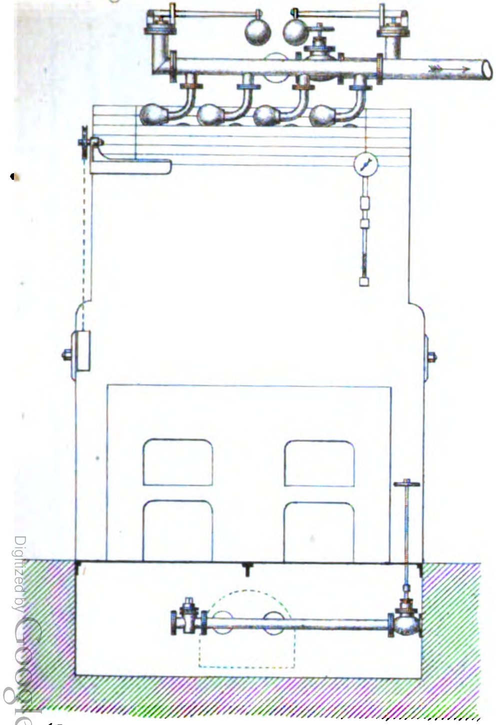


Fig. 3. *Transverse Section at XX.*

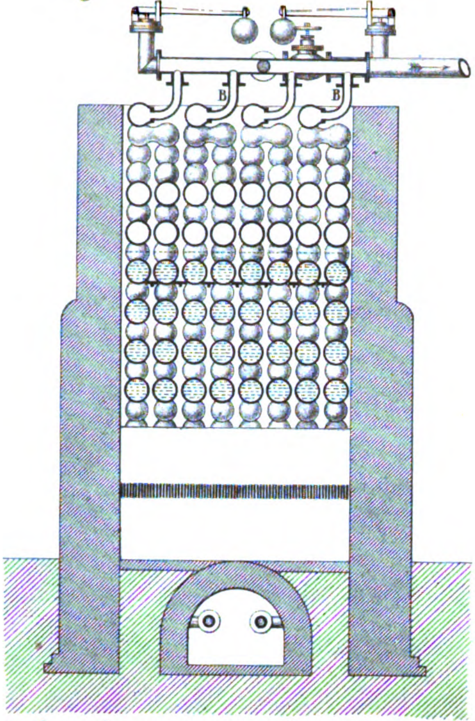
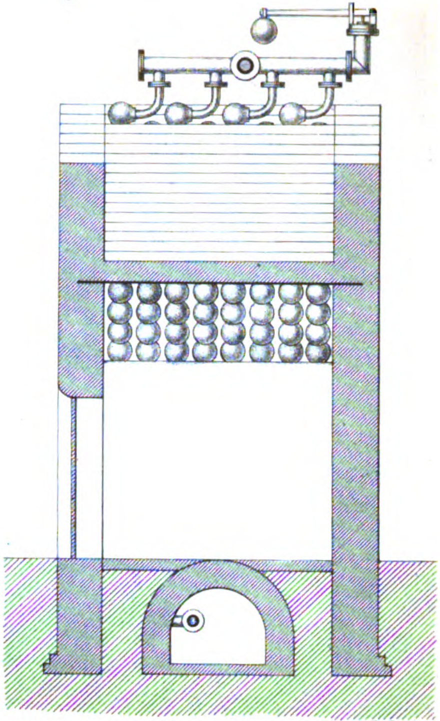
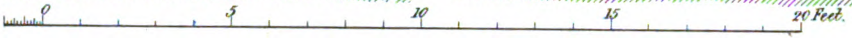


Fig. 4. *Transverse Section at ZZ.*



(Proceedings Inst. M. E. 1864. Page 61.)

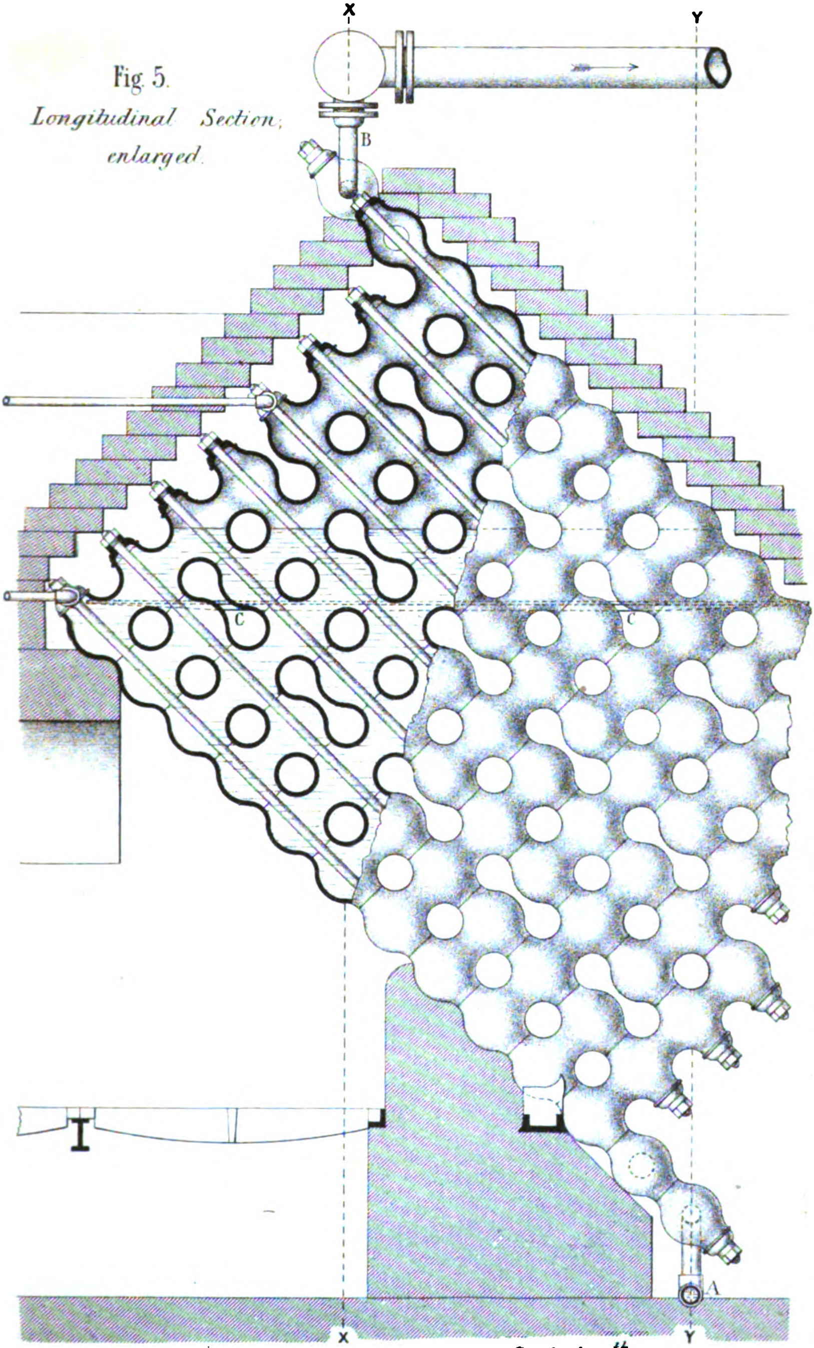
Scale 1/60th.



CAST IRON STEAM BOILER.

Fig. 5.

Longitudinal Section; enlarged.



(Proceedings Inst. M. E. 1864. Page 61.)

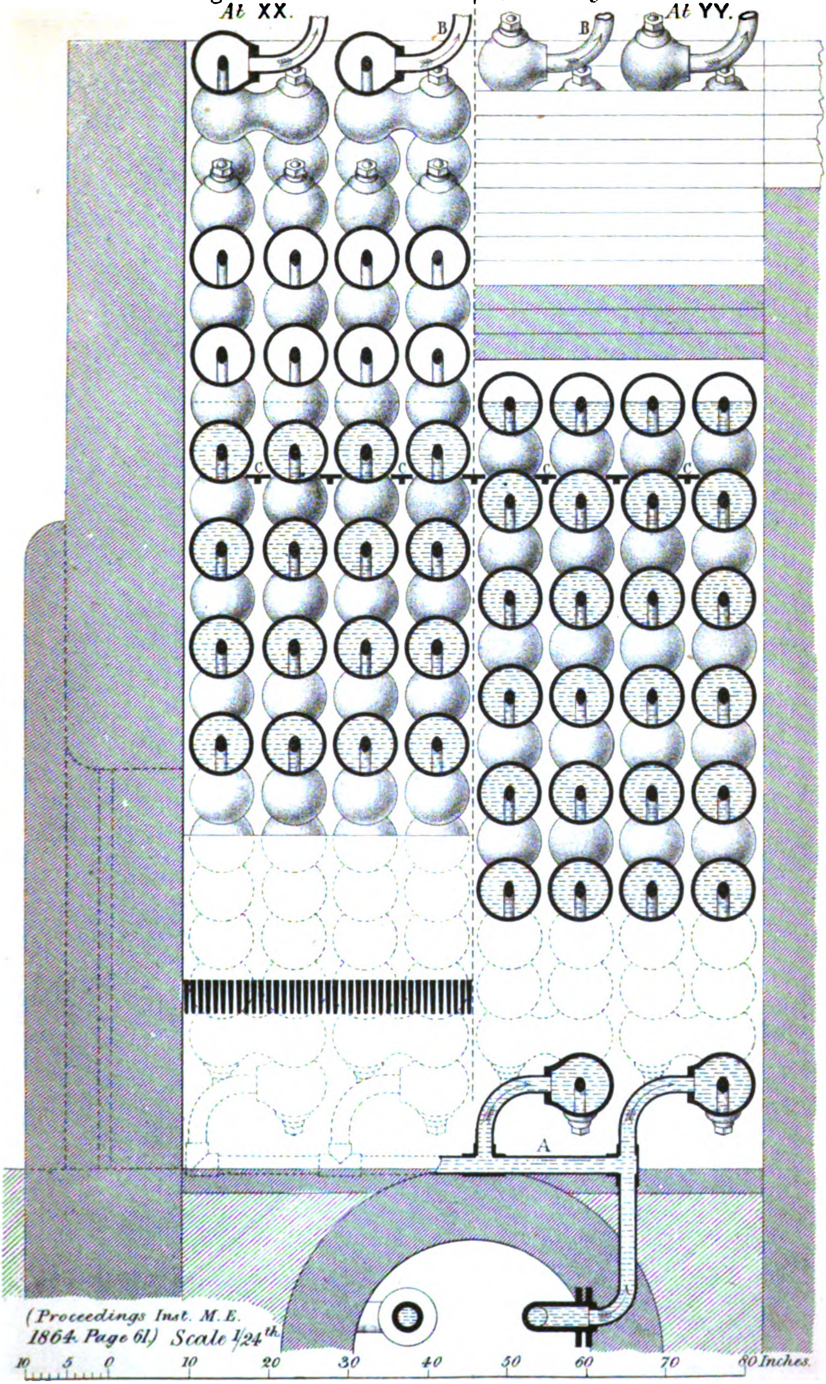
Scale $\frac{1}{24}$th

10 5 0 10 20 30 40 50 60 70 80 Inches

CAST IRON STEAM BOILER.

Plate 22.

Fig. 6. *Transverse Section, enlarged.*



CAST IRON STEAM BOILER.

Plate 23.

Detail of one "Unit" of Boiler.

Fig. 7. *Transverse Section.*

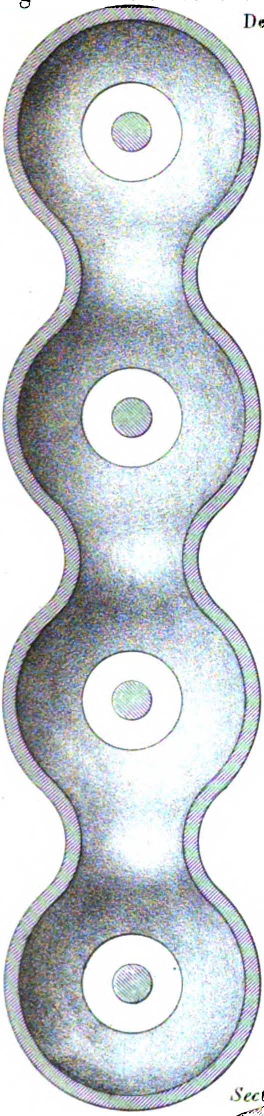


Fig. 8. *Longitudinal Section.*

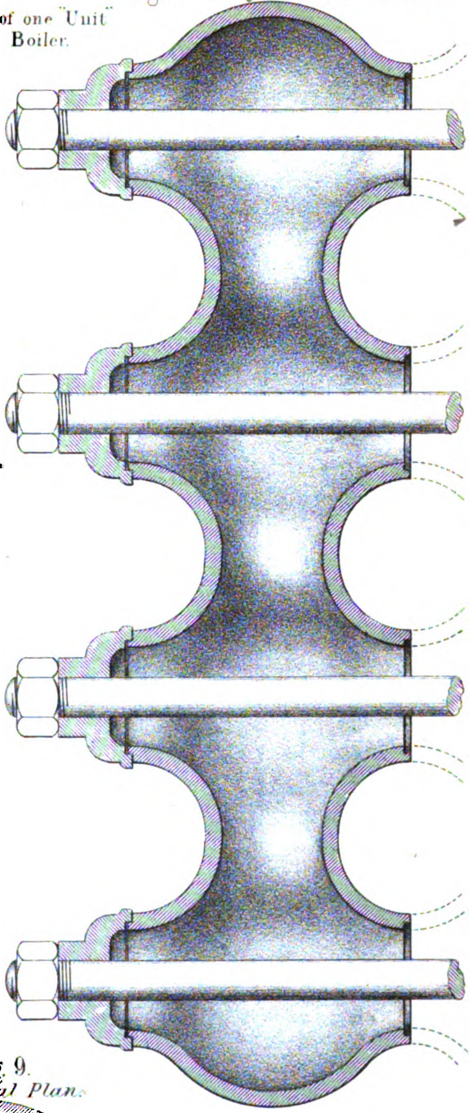


Fig. 9. *Sectional Plan.*

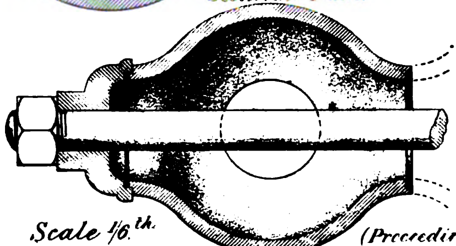
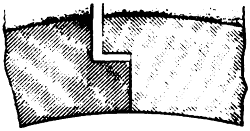
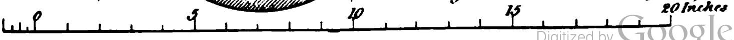


Fig. 10. *Full Size Section of Joint.*



Scale 1/6th.



(Proceedings Inst. M.E. 1864. Page 61.)

DISTRIBUTION OF WEIGHT IN LOCOMOTIVES. *Plate 24.*

Fig. 1. *Four Wheeled Engine, Coupled.*
Inside Cylinders.

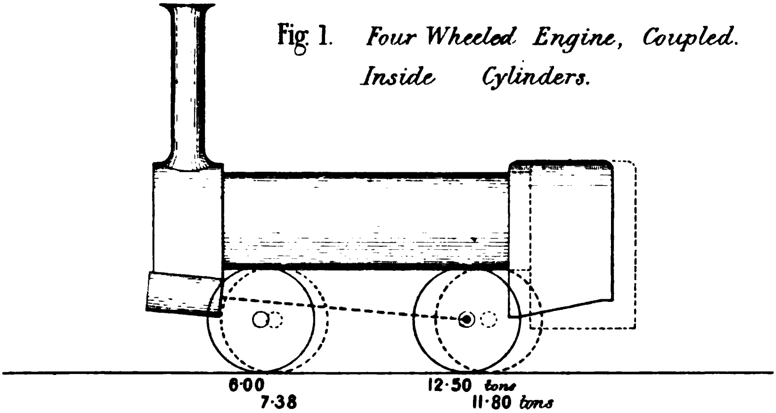


Fig. 2. *Four Wheeled Engine, Coupled.*
Outside Cylinders.

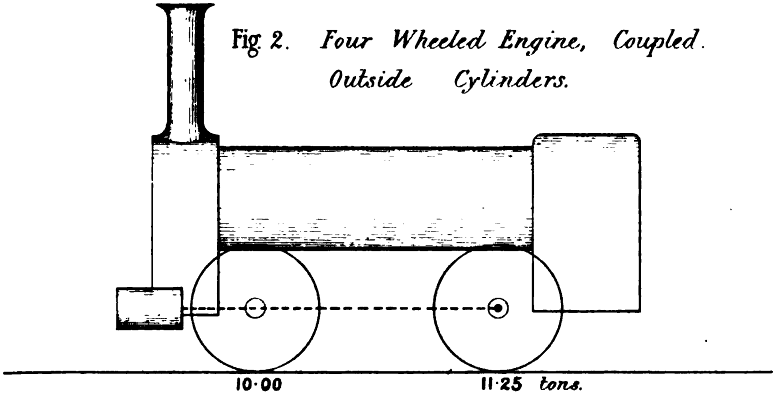
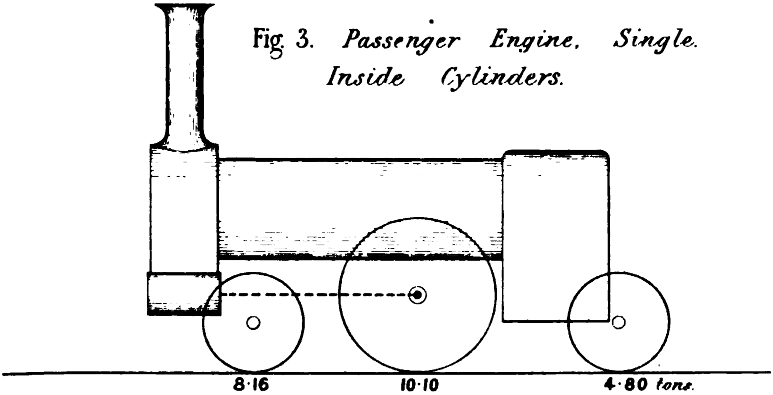
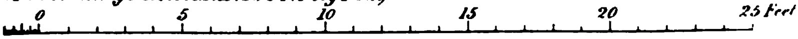


Fig. 3. *Passenger Engine, Single.*
Inside Cylinders.



(Proceedings Inst. M.E. 1864. Page 92.)

Scale 1/80th.



DISTRIBUTION OF WEIGHT IN LOCOMOTIVES. *Plate 25.*

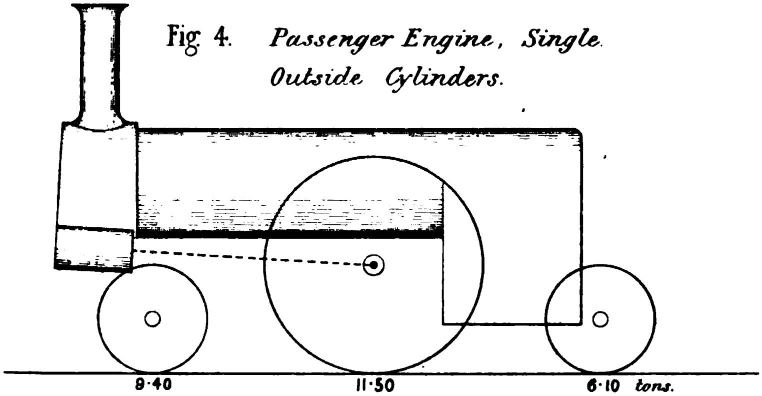


Fig. 4. *Passenger Engine, Single.*
Outside Cylinders.

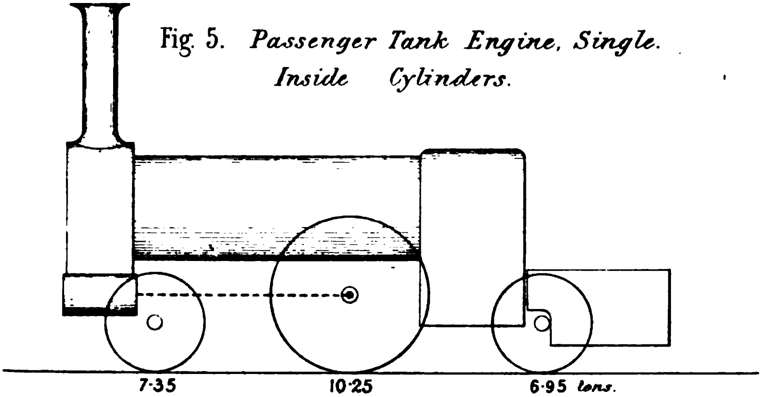


Fig. 5. *Passenger Tank Engine, Single.*
Inside Cylinders.

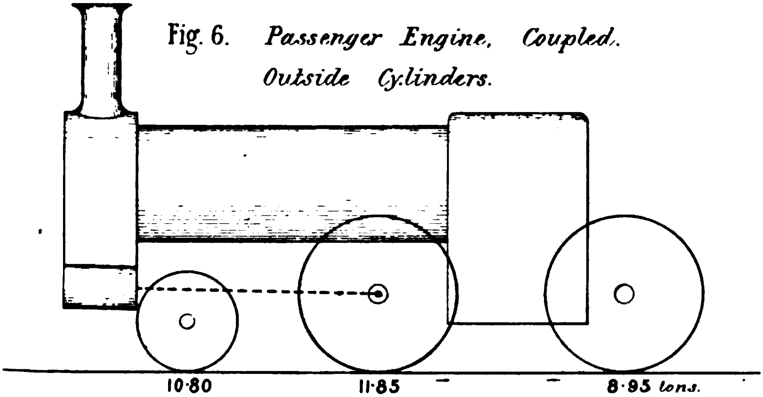


Fig. 6. *Passenger Engine, Coupled.*
Outside Cylinders.

(Proceedings Inst. M.E. 1864. Page 92.)

Scale 1/80th.

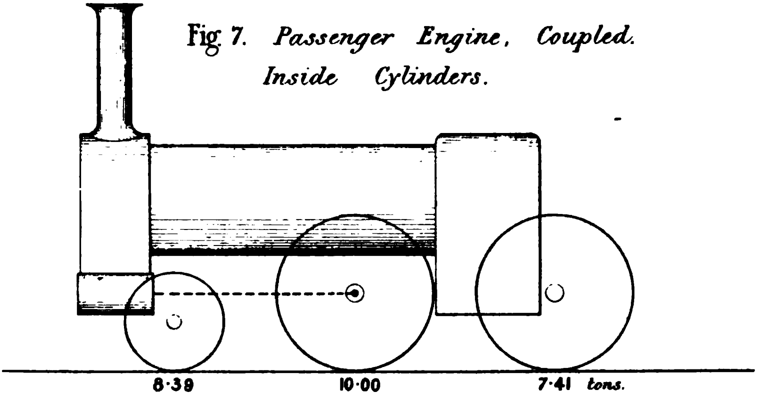


Fig. 7. *Passenger Engine, Coupled. Inside Cylinders.*

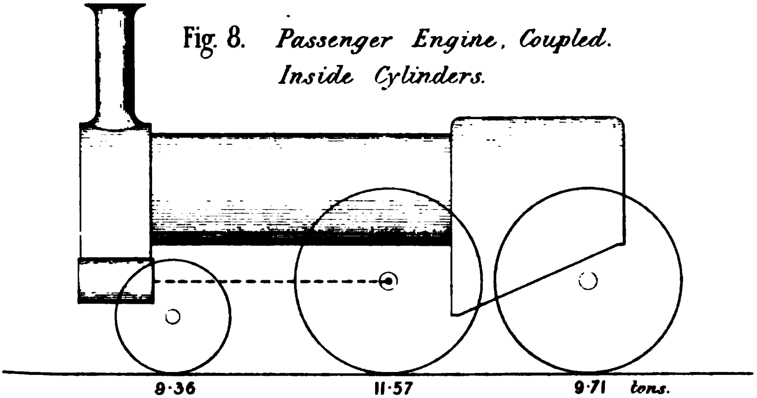


Fig. 8. *Passenger Engine, Coupled. Inside Cylinders.*

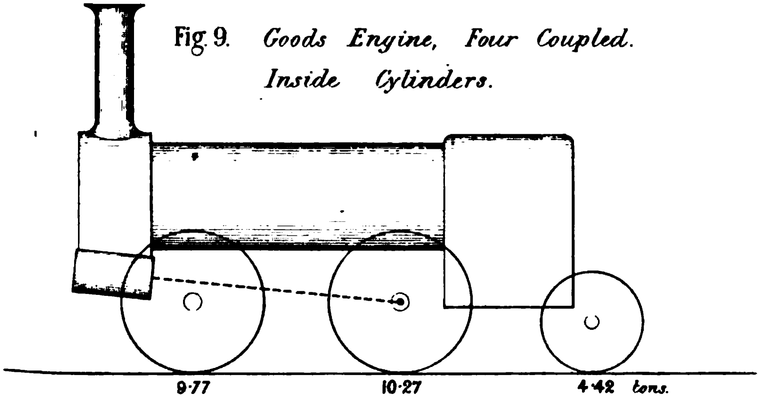


Fig. 9. *Goods Engine, Four Coupled. Inside Cylinders.*

(Proceedings Inst. M. E. 1864. Page 92.)

Scale 1/80th.

DISTRIBUTION OF WEIGHT IN LOCOMOTIVES. *Plate 27.*

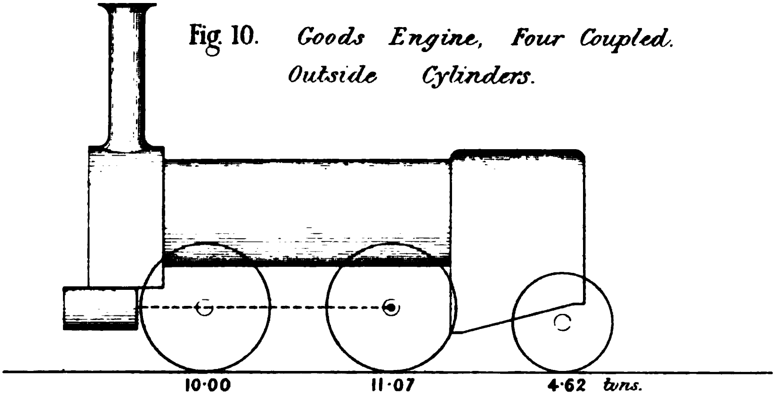


Fig. 10. *Goods Engine, Four Coupled. Outside Cylinders.*

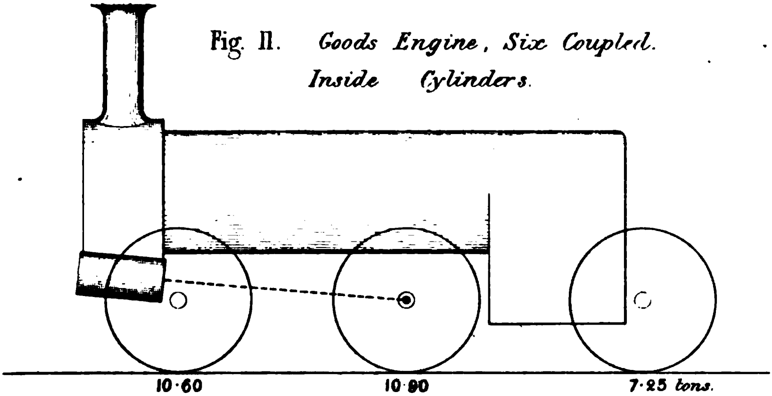


Fig. 11. *Goods Engine, Six Coupled. Inside Cylinders.*

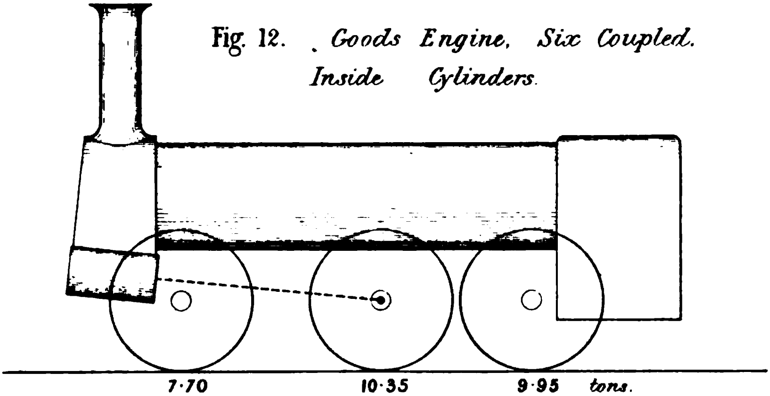


Fig. 12. *Goods Engine, Six Coupled. Inside Cylinders.*

(Proceedings Inst. M.E. 1864. Page 92.)

Scale $\frac{1}{80}$*th*

0 5 10 15 20 25 Feet.

DISTRIBUTION OF WEIGHT IN LOCOMOTIVES. *Plate 28.*

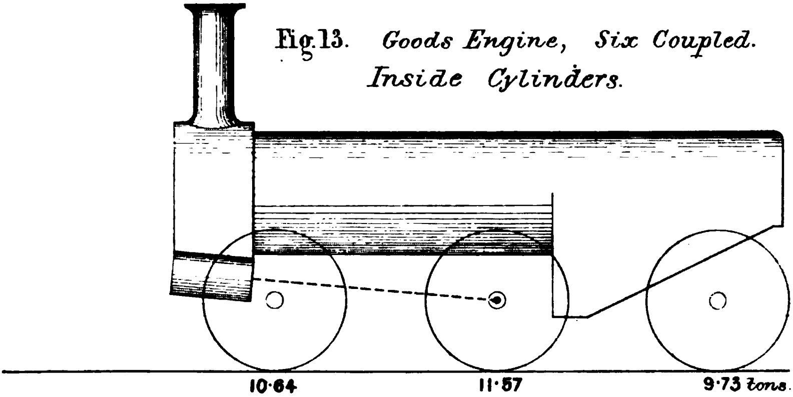


Fig. 13. *Goods Engine, Six Coupled. Inside Cylinders.*

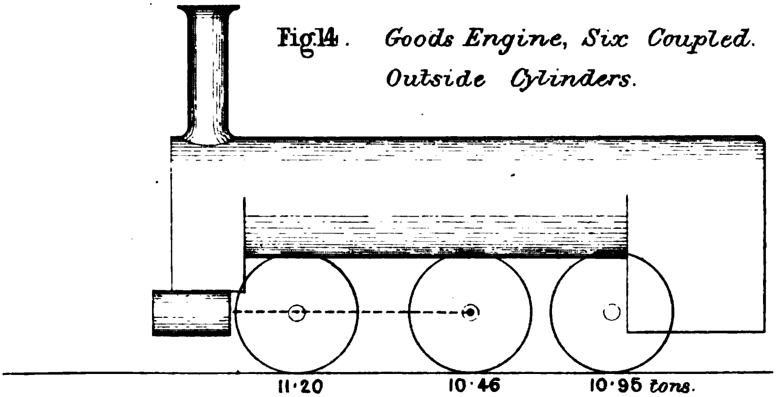


Fig. 14. *Goods Engine, Six Coupled. Outside Cylinders.*

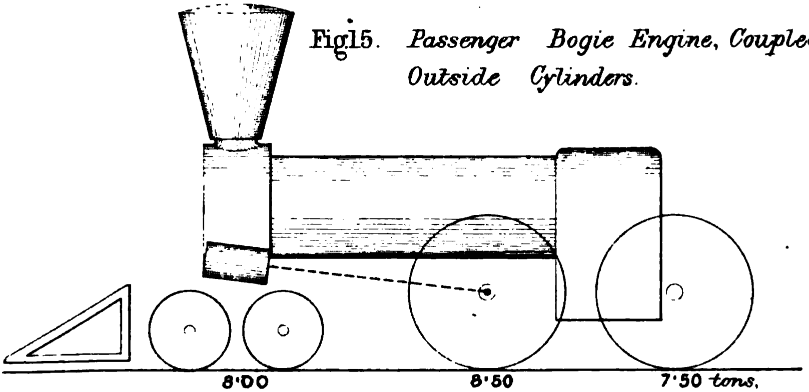
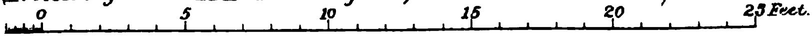


Fig. 15. *Passenger Bogie Engine, Coupled. Outside Cylinders.*

(Proceedings Inst. M.E. 1864. Page 92.)

Scale 1/80th



DISTRIBUTION OF WEIGHT IN LOCOMOTIVES.

Plate 29.

Fig.16.

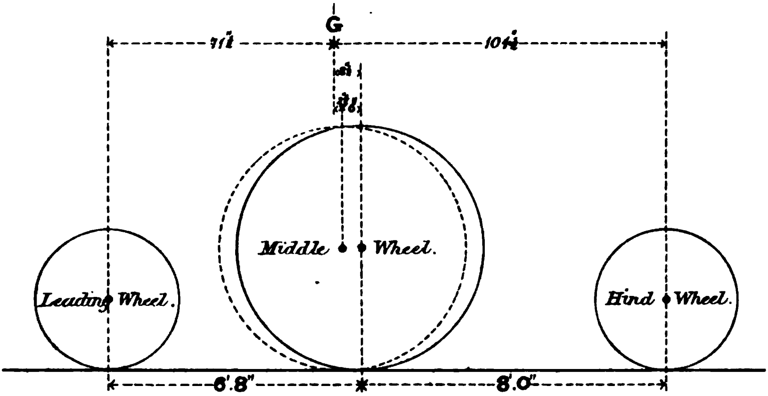


Fig.17.

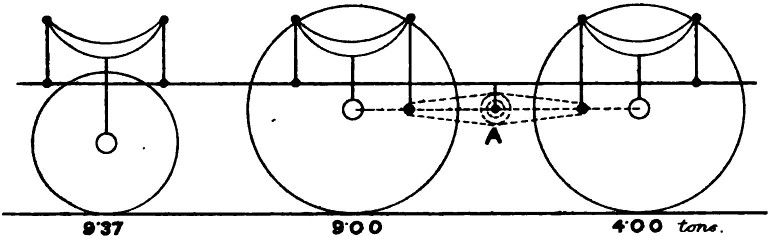


Fig.18.

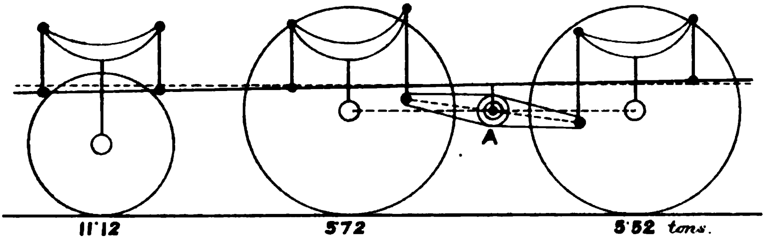
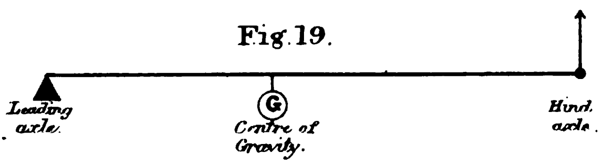


Fig.19.

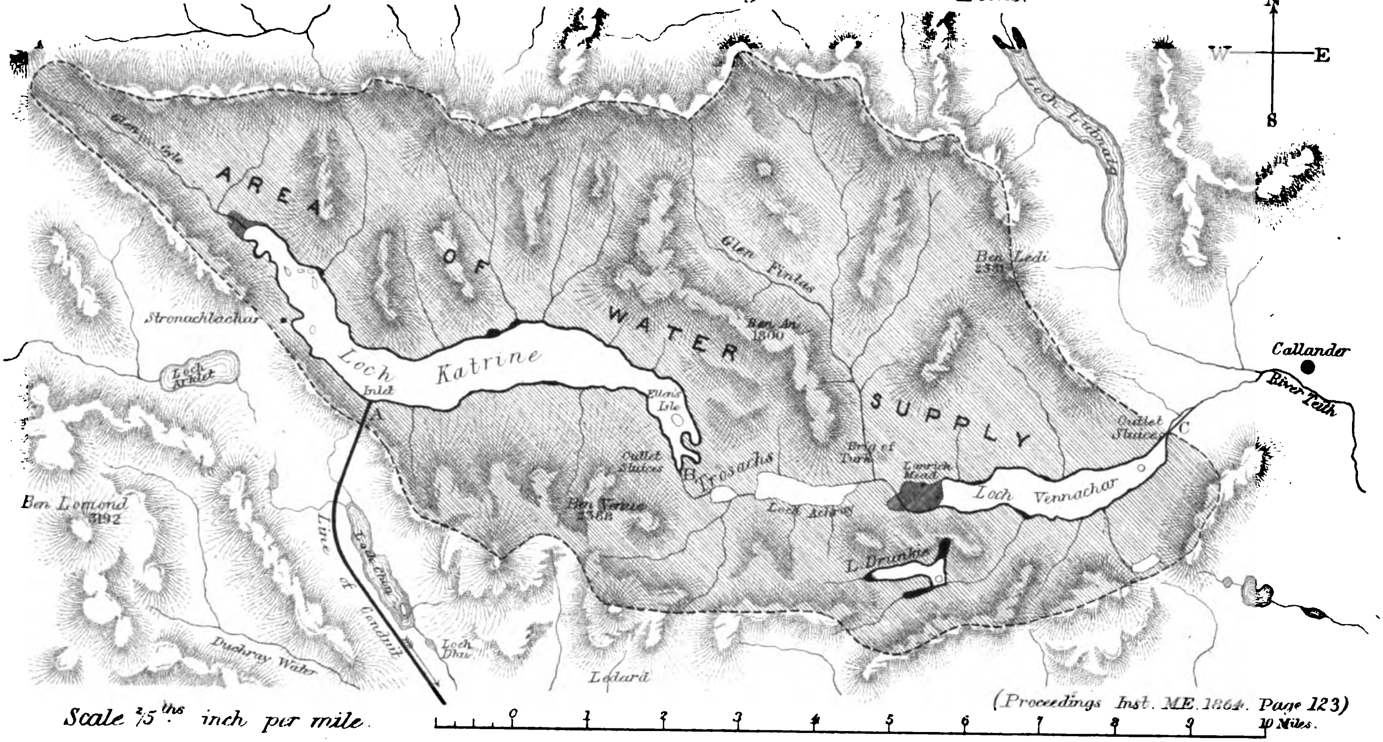


(Proceedings Inst. M.E. 1864. Page 92.)

Scale 1/60th.

LOCH KATRINE WATER WORKS.

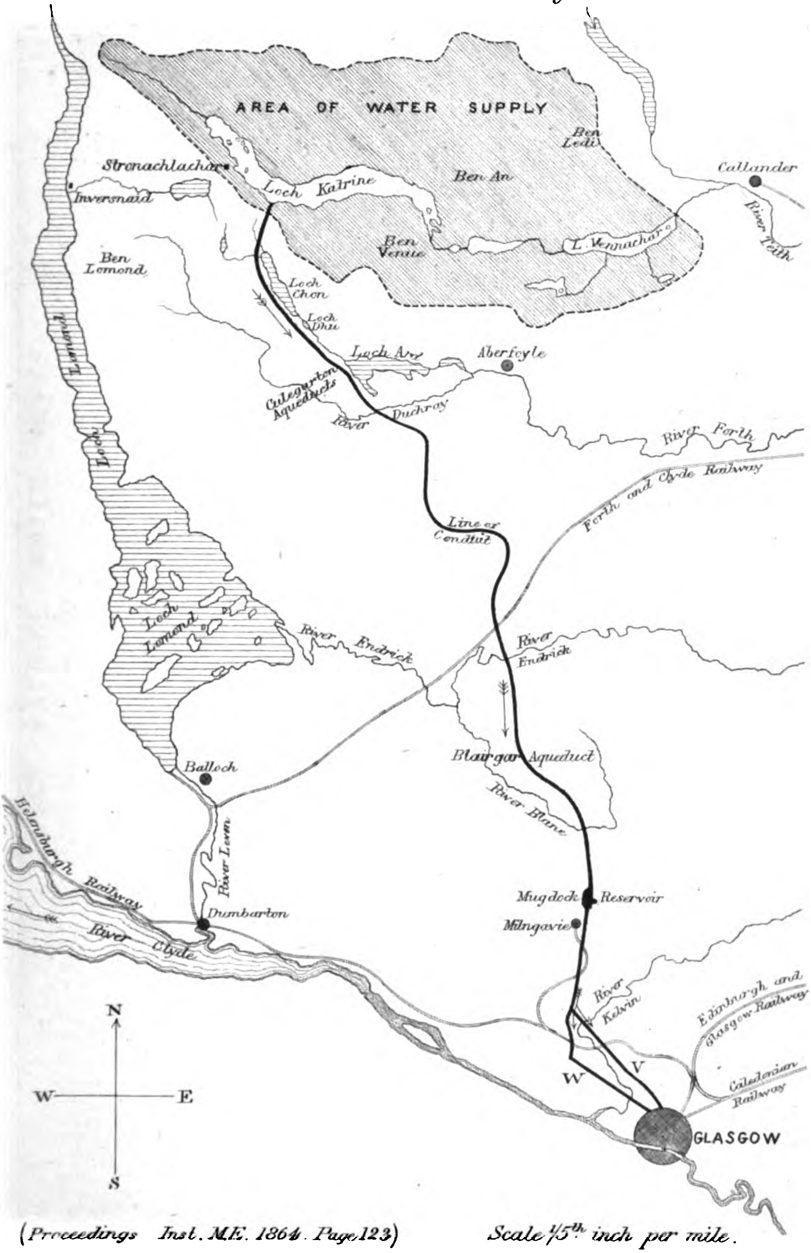
Fig. 1. General Plan of Drainage Area and Lochs.



(Proceedings Inst. M.E. 1864. Page 123)

LOCH KATRINE WATER WORKS. *Plate 31.*

Fig. 2. *General Plan showing Line of Conduit from Loch Katrine to Glasgow.*

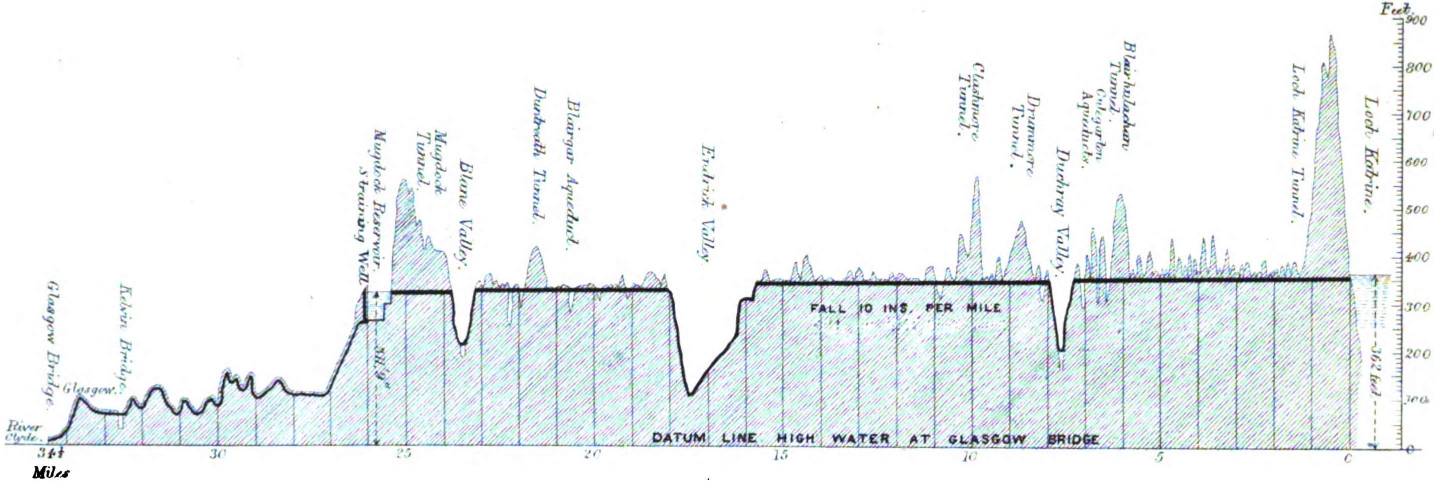


(*Proceedings Inst. M.E. 1864. Page 123*) *Scale 1/5th inch per mile.*

0 5 10 15 20 *Miles.*

LOCH KATRINE WATER WORKS.

Fig. 3. *Longitudinal Section from Loch Katrine to Glasgow.*

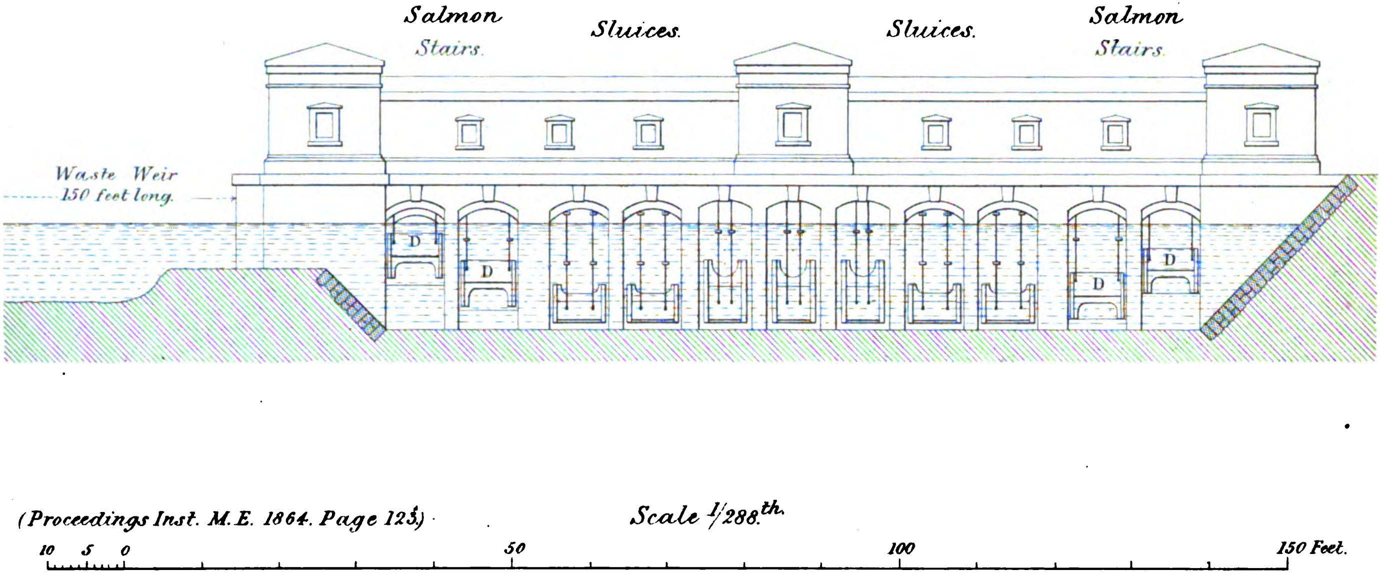


Horizontal Scale 1/5th inch per mile.

(Proceedings Inst. M.E. 1864. Page 123)

LOCH KATRINE WATER WORKS.

Fig. 4. Loch Vennachar Outlet.



Scale 1/288th.

(Proceedings Inst. M.E. 1864. Page 123.)

LOCH KATRINE WATER WORKS.

Plate 34.

Loch Vennachar Outlet.

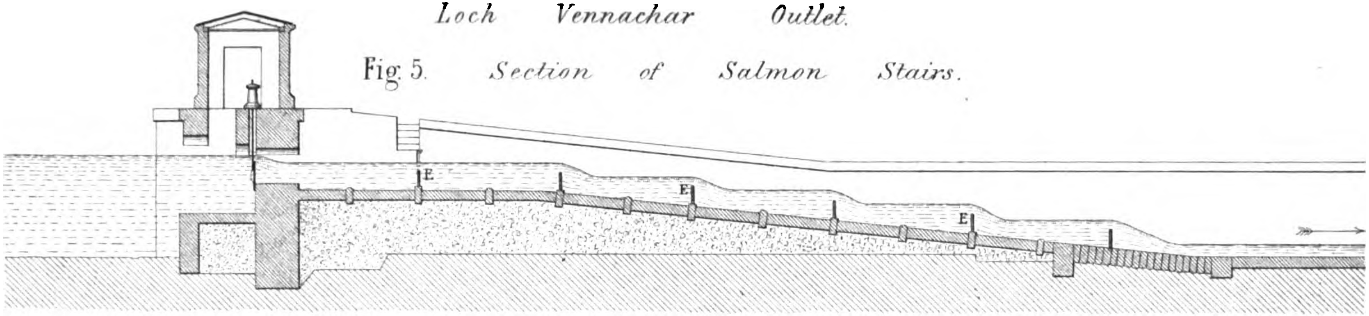
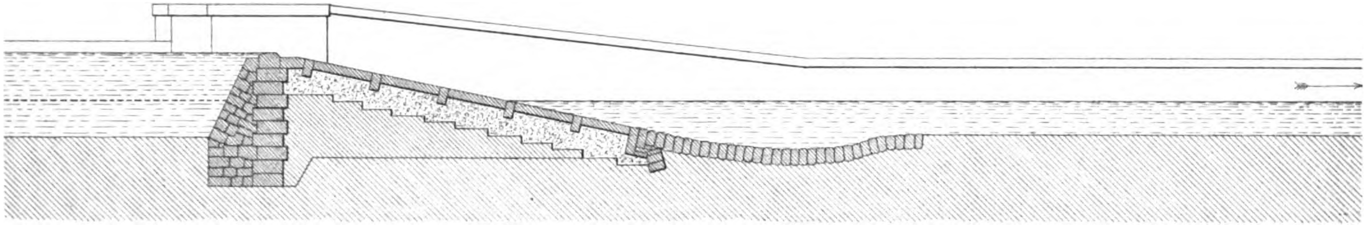


Fig. 5. *Section of Salmon Stairs.*

Fig. 6. *Section of Waste Weir.*



Scale 1/288th.

(Proceedings Inst. M.E. 1864. Page 123.)

LOCH KATRINE WATER WORKS.

Loch Vennachar Outlet.

Detail of Salmon Sluices.

Fig. 7.

Inside Elevation of Sluice.

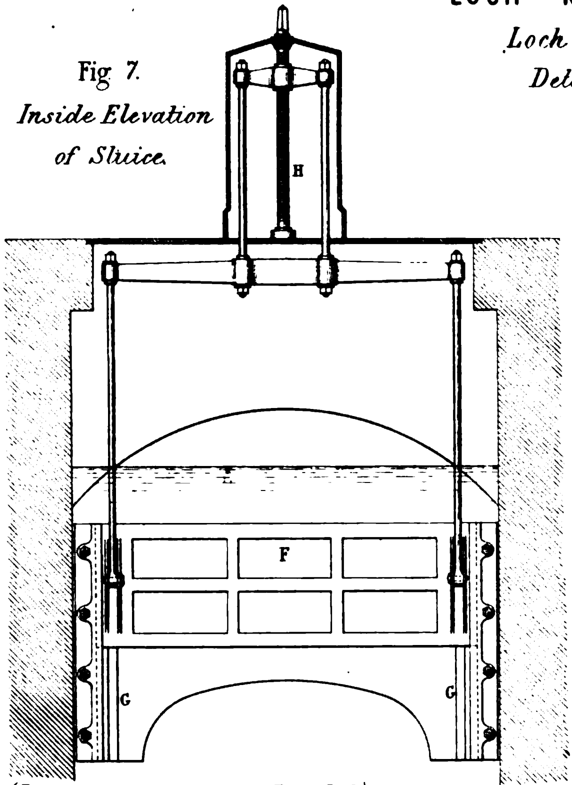


Fig. 8.

Sectional Plan.

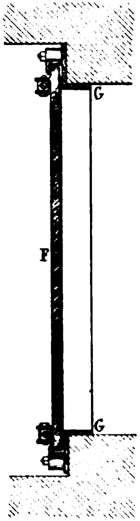
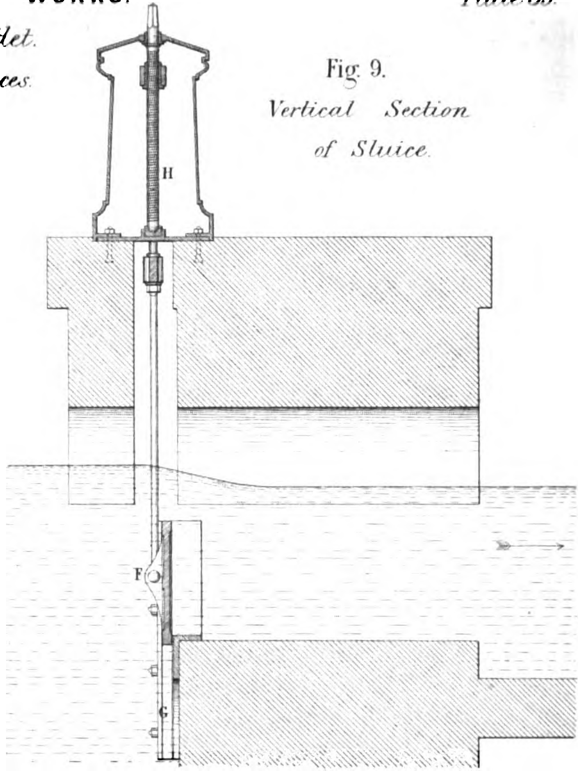


Fig. 9.

Vertical Section of Sluice.

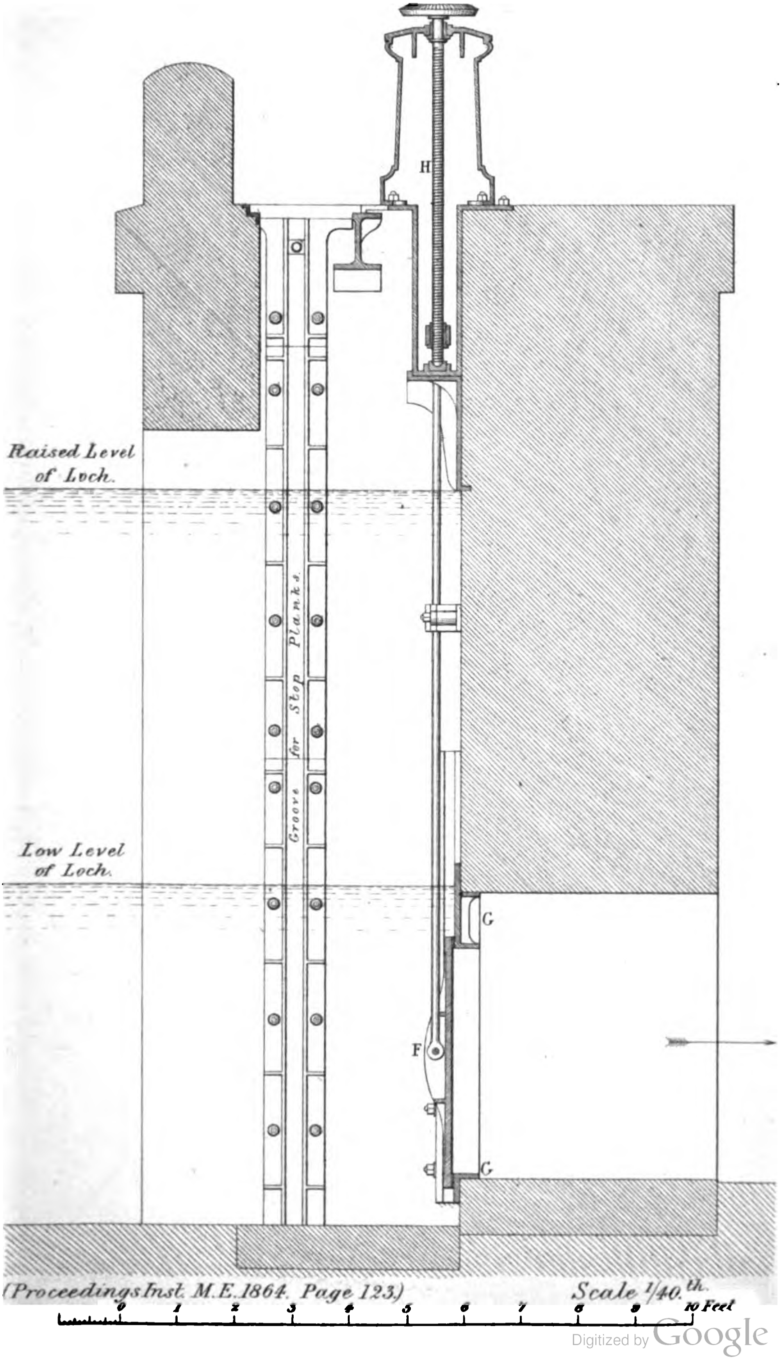


Scale 1/40th. 0 1 2 3 4 5 6 7 8 9 10 Feet.

(Proceedings Inst. M.E. 1864. Page 123.)

LOCH KATRINE WATER WORKS.

Fig. 10. *Inlet Sluice to Aqueduct from Loch Katrine.*



(Proceedings Inst. M.E. 1864. Page 123.) *Scale 1/40th.*

LOCH KATRINE WATER WORKS.

Plate 37.

Fig. 11. *Inside Elevation of Inlet Sluice. Scale 1/40th.*

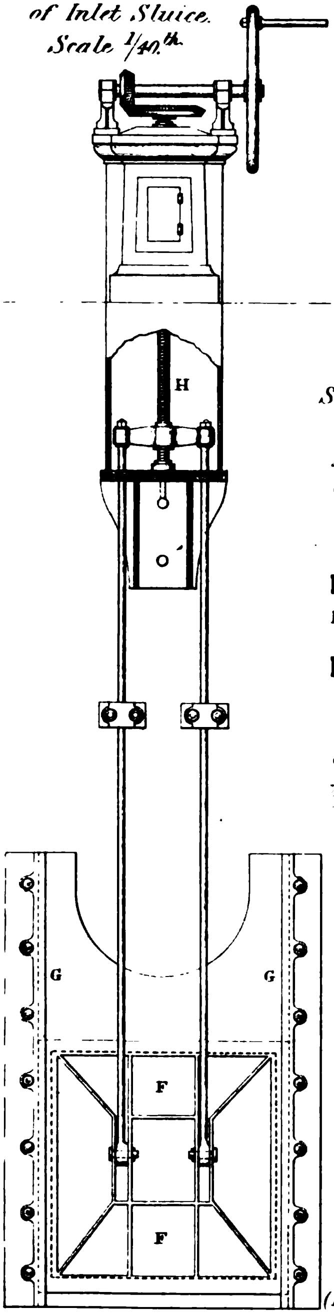
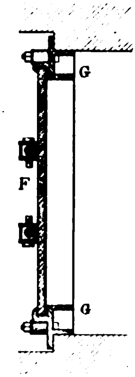


Fig. 12. *Sectional Plan.*



Sections of Aqueduct in excavation.

Fig. 13. *Tunnel in Rock.*

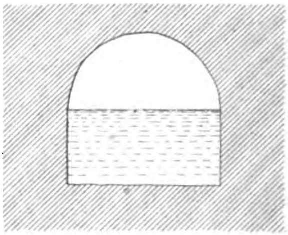


Fig. 14. *Tunnel in material not water-tight.*

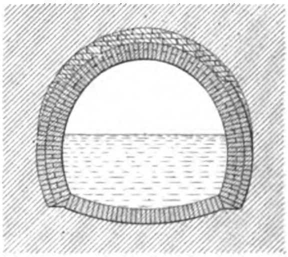
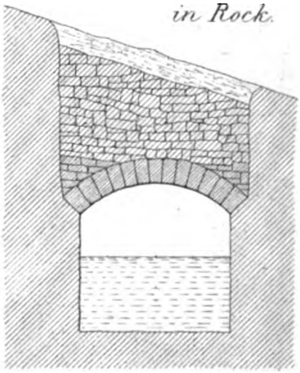


Fig. 15. *Open Cutting in Rock.*



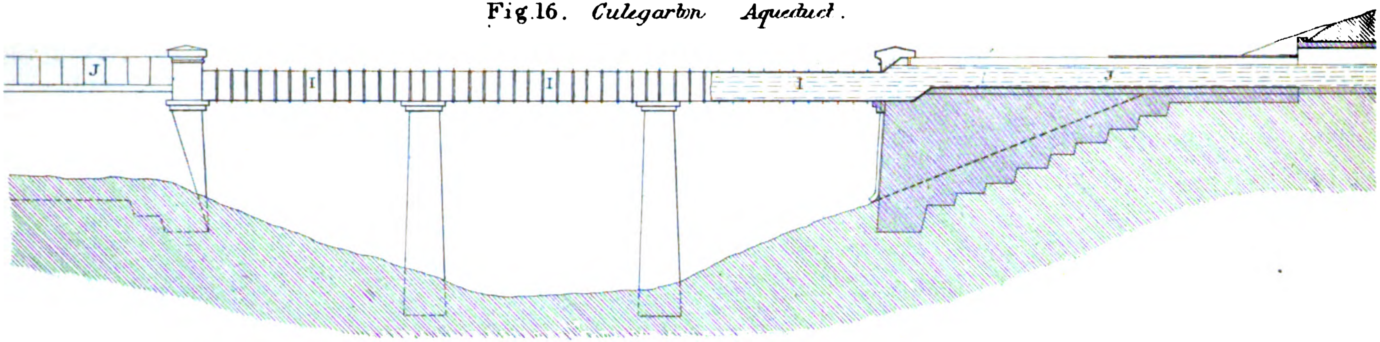
Scale 1/120th.

0 5 10 Feet.

(Proceedings Inst. M.E. 1864. Page 123)

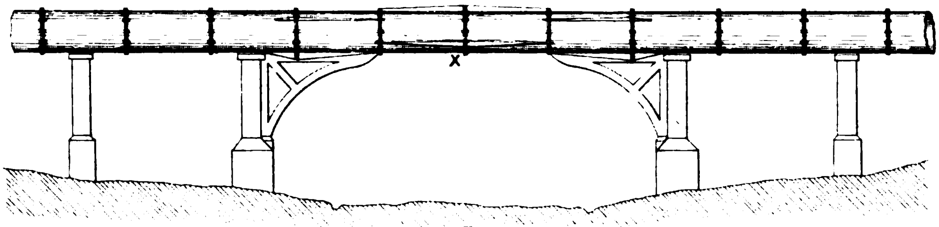
LOCH KATRINE WATER WORKS.

Fig.16. Culegarbn Aqueduct.



Scale 1/480th 0 50 100 150 200 Feet.

Fig.17. 48 inch Syphon Pipe crossing Aberfoyle Road.



(Proceedings Inst. M.E. 1864. Page 123)

Scale 1/240th 10 5 0 10 20 30 40 50 Feet.

LOCH KATRINE WATER WORKS.

Transverse Sections of Culegarton Aqueduct.

Fig. 18. *Thro' Wrought Iron Tube.*

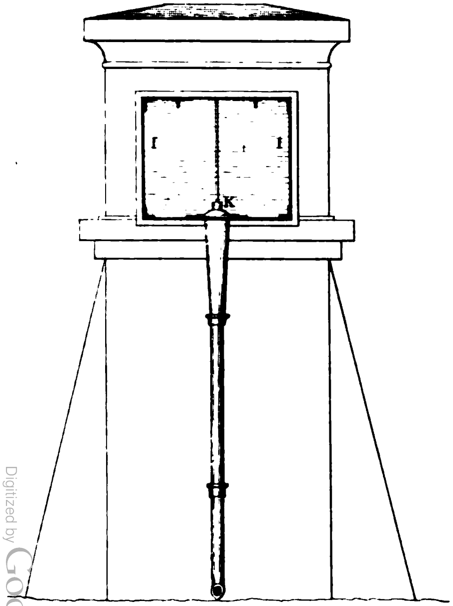
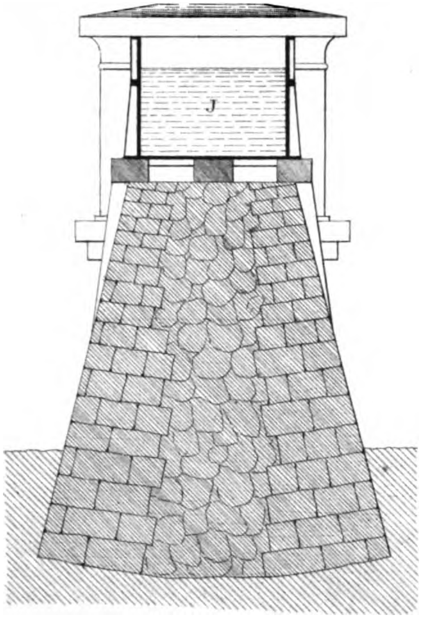


Fig. 19. *Thro' Cast Iron Trough.*



Scale 1/120th 10 5 0 10 20 *Feet.*

48 *inch Syphon Pipe crossing Aberfoyle Road.*

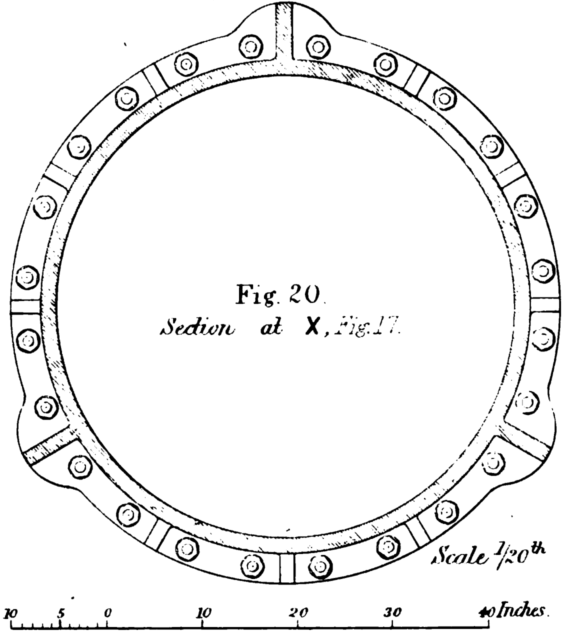


Fig. 20.
Section at **X**, *Fig. 17.*

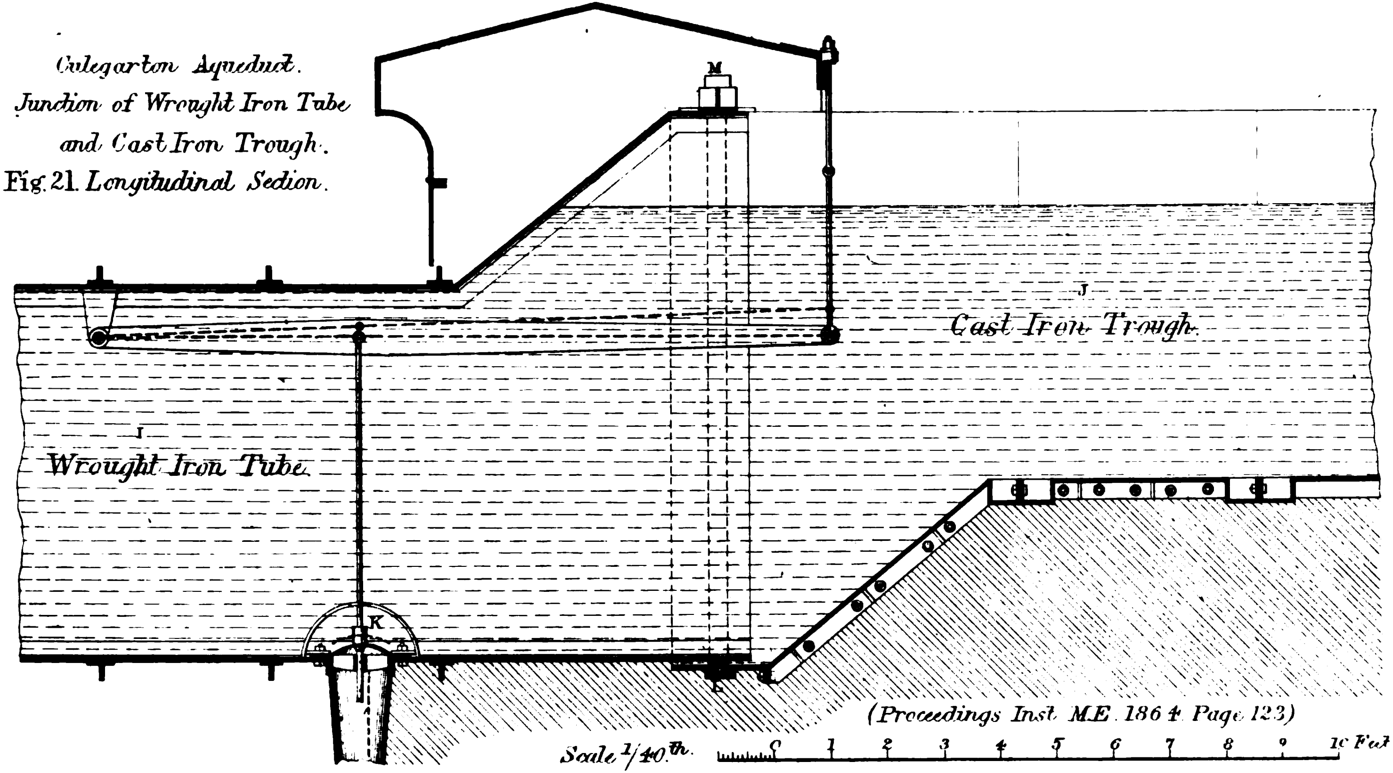
Scale 1/20th

(Proceedings Inst. M.E. 1864. Page 123)

LOCH KATRINE WATER WORKS

Plate 40

Culegarton Aqueduct.
Junction of Wrought Iron Tube
and Cast Iron Trough.
Fig. 21. Longitudinal Section.

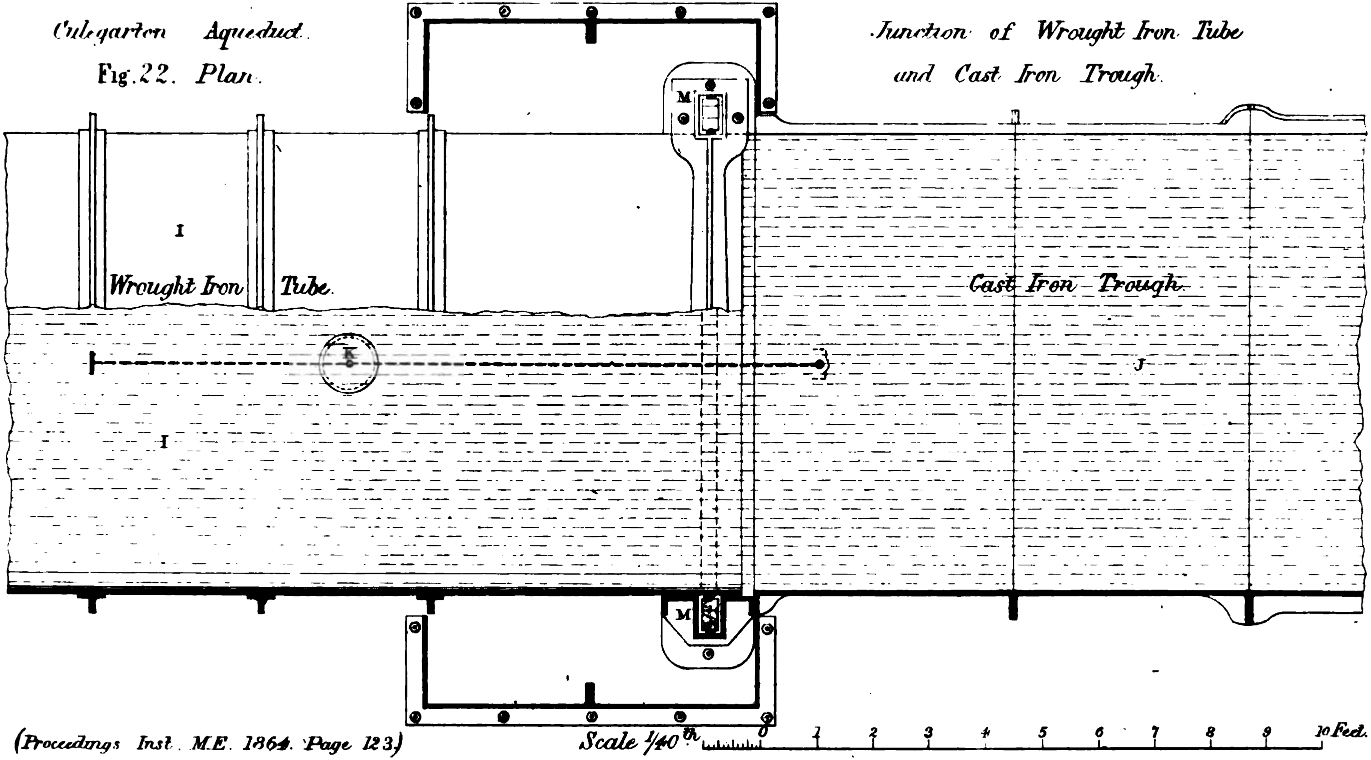


(Proceedings Inst. M.E. 1864 Page 123)

LOCH KATRINE WATER WORKS.

Culegarton Aqueduct.
Fig. 22. Plan.

Junction of Wrought Iron Tube
and Cast Iron Trough.



(Proceedings Inst. M.E. 1864. Page 123.)

LOCH KATRINE WATER WORKS. *Plate 42.*

Culegarton Aqueduct.

Junction of Wrought Iron Tube and Cast Iron Trough.

Fig. 23. *Section of India-rubber Bolster at Bottom.*

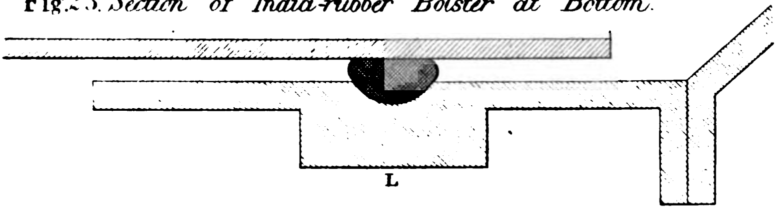
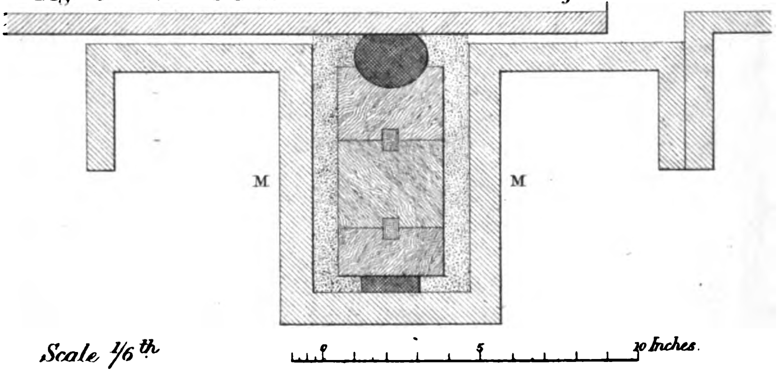


Fig. 24. *Section of India-rubber Bolster and Wedges at Sides.*



Scale 1/6th

Sections of Joints of 48 inch Syphon Pipes
Scale one quarter full size.

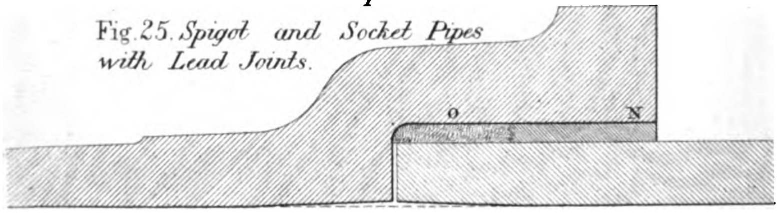
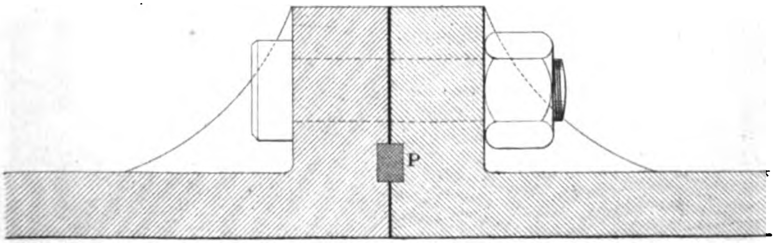


Fig. 25. *Spigot and Socket Pipes with Lead Joints.*

Fig. 26. *Flanged Pipes with India-rubber Joints.*



(Proceedings Inst. M.E. 1864. Page 123)

Scale 1/4th

Plate 43.

LOCH KATRINE WATER WORKS.

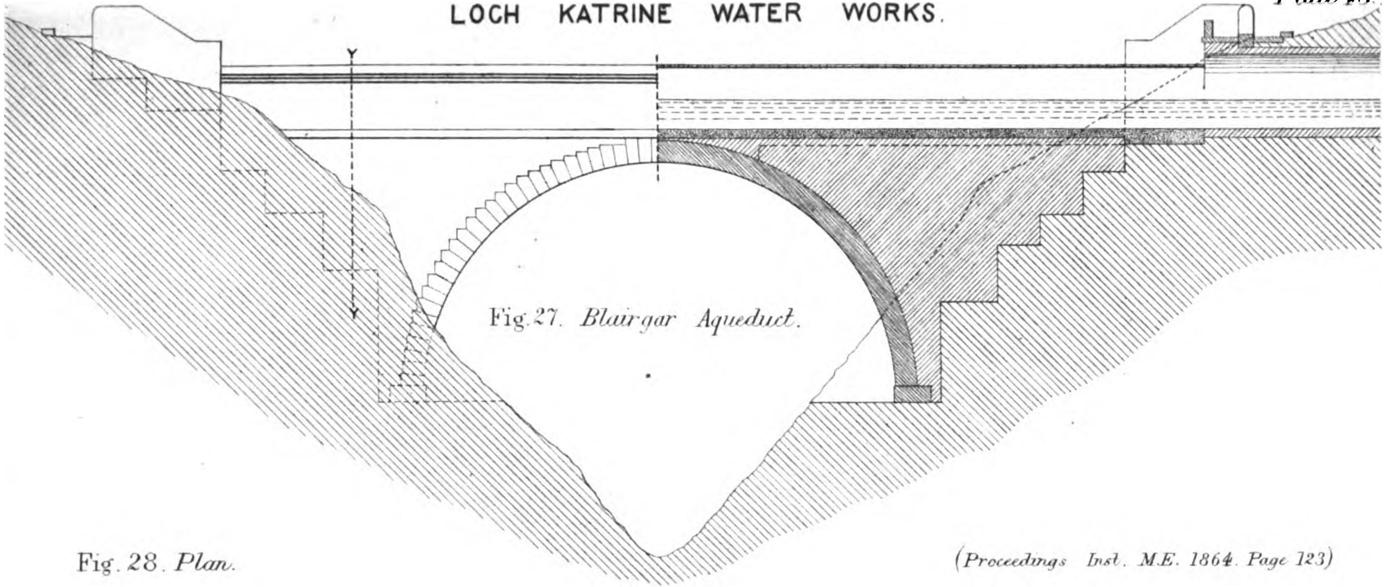
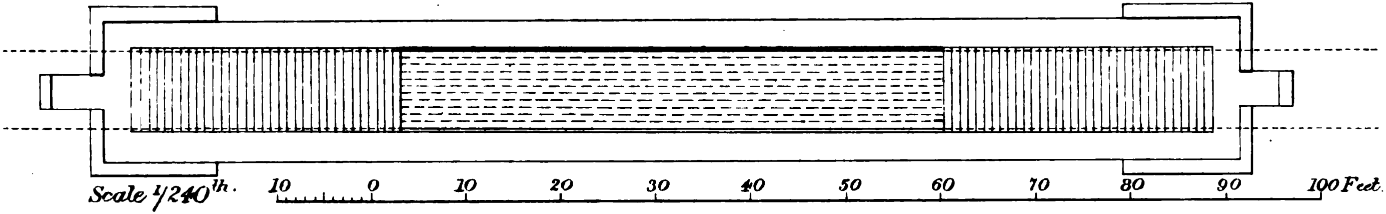


Fig. 27. Blairgar Aqueduct.

Fig. 28. Plan.

(Proceedings Inst. M.E. 1864. Page 123)



LOCH KATRINE WATER WORKS.

Blairgar Aqueduct.

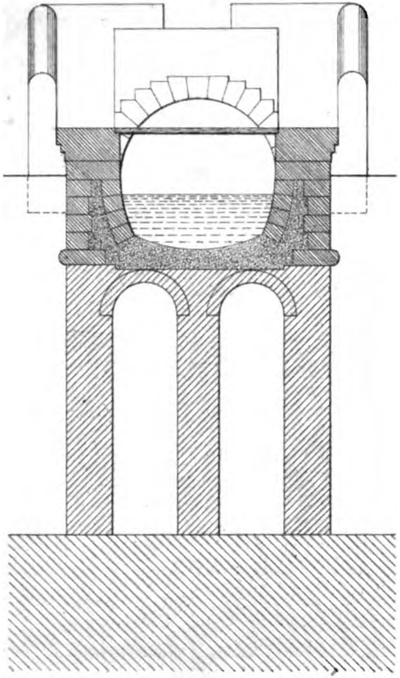


Fig. 29.
Transverse Section at **YY** (Fig. 27)

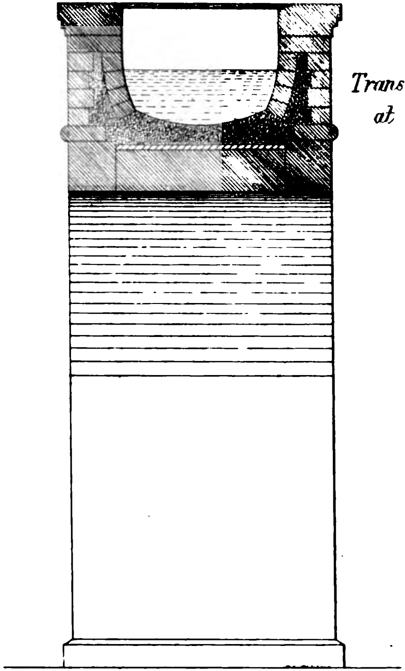
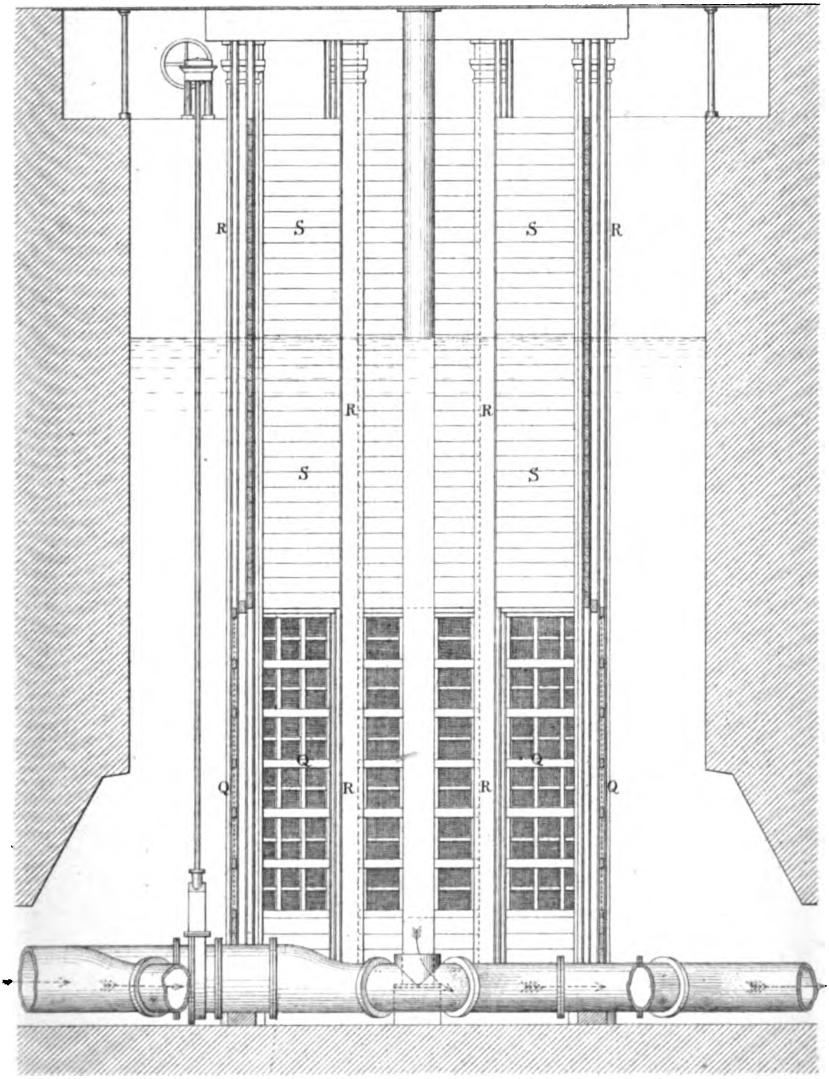


Fig. 30.
Transverse Section at Centre.

Scale 1/120th 10 5 0 10 20 30 *Feet*.

Mugdock Straining Well.

Fig. 31. *Vertical Section.*



Scale 1/140th.

(Proceedings Inst. M. E. 1864. Page 123)

LOCH KATRINE WATER WORKS. *Plate 46.*

Mugdock Straining Well.

Fig. 32. *Vertical Transverse Section.*

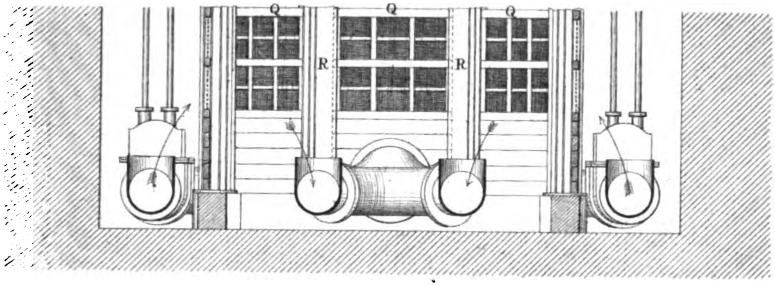
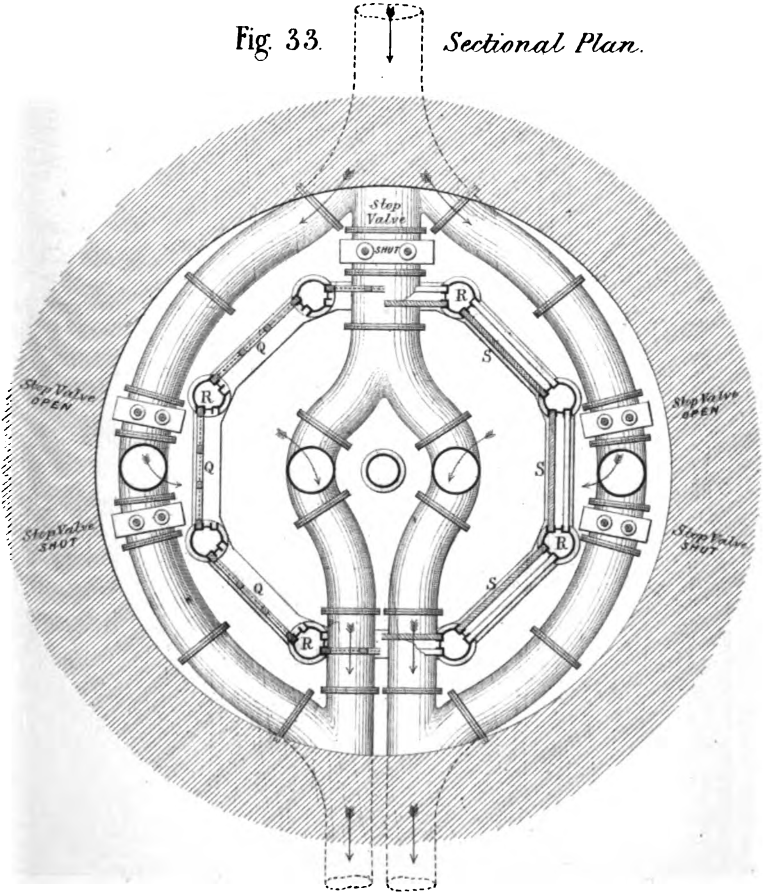


Fig. 33. *Sectional Plan.*



(Proceedings Inst. M.E. 1864. Page 123)

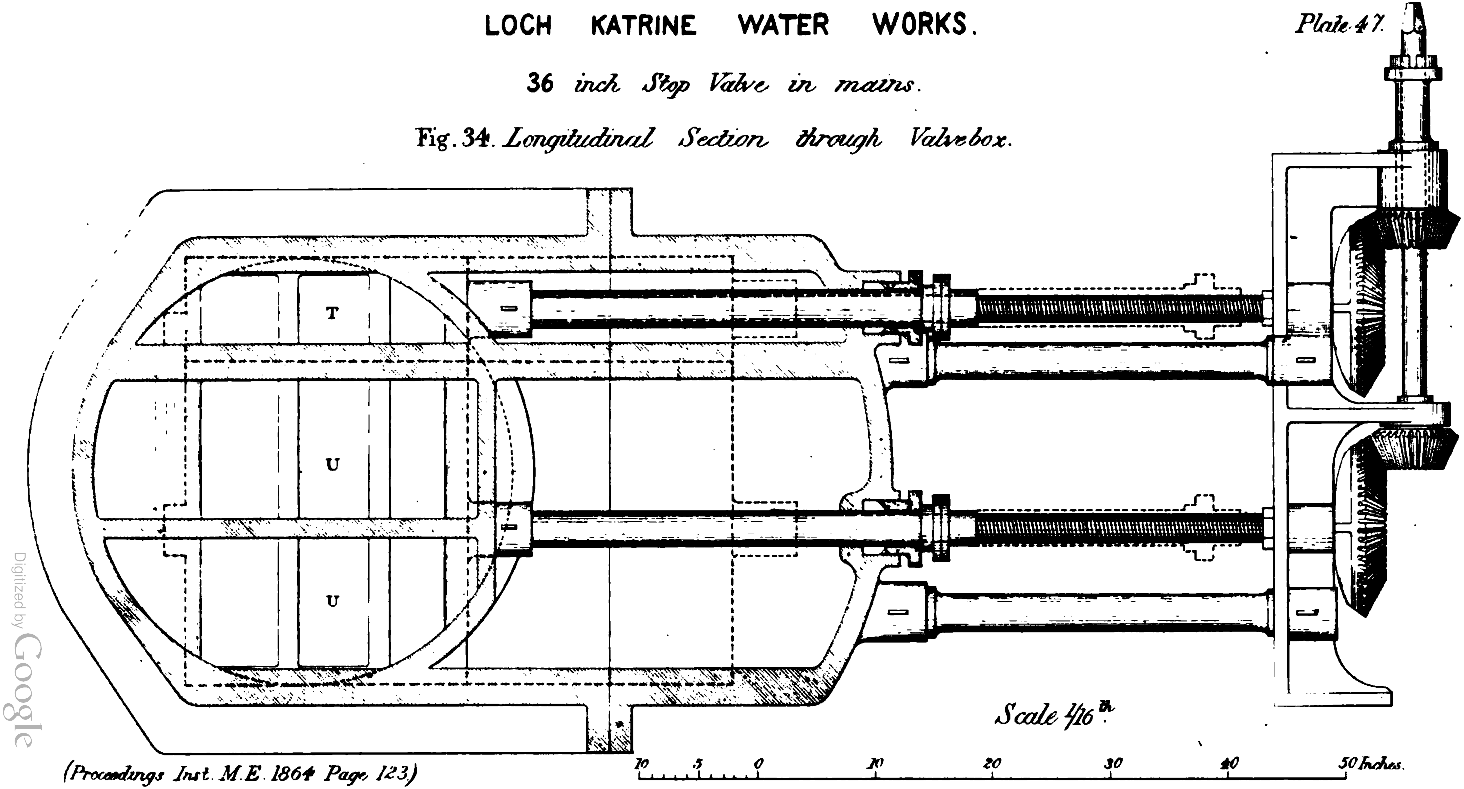
Scale 1/140th.

10 5 0 10 20 30 Feet.

LOCH KATRINE WATER WORKS.

36 inch Stop Valve in mains.

Fig. 34. Longitudinal Section through Valvebox.



(Proceedings Inst. M.E. 1864 Page 123)

LOCH KATRINE WATER WORKS.

Plate 48.

36 inch Stop Valve
in mains.

Fig 35. *Sectional Plan.*

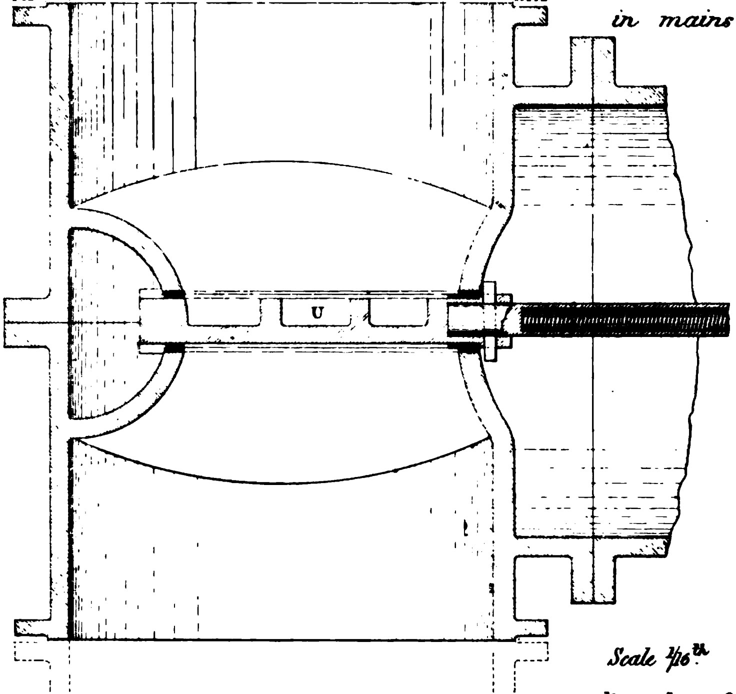
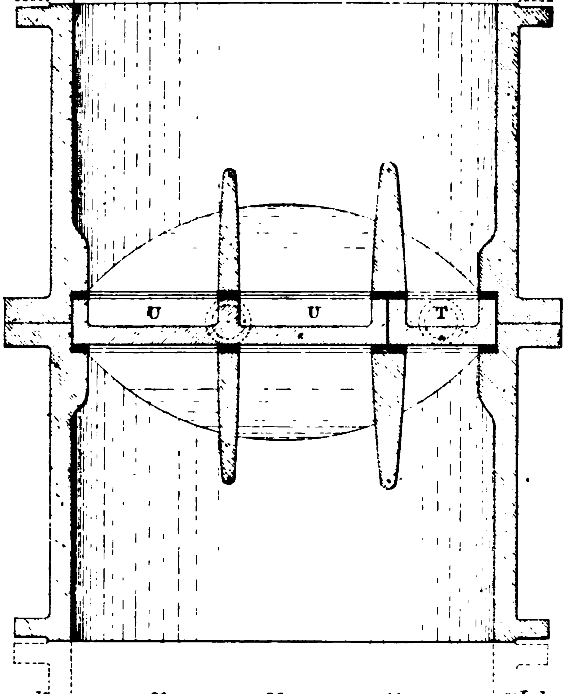
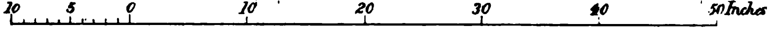


Fig. 36. *Transverse Section.*



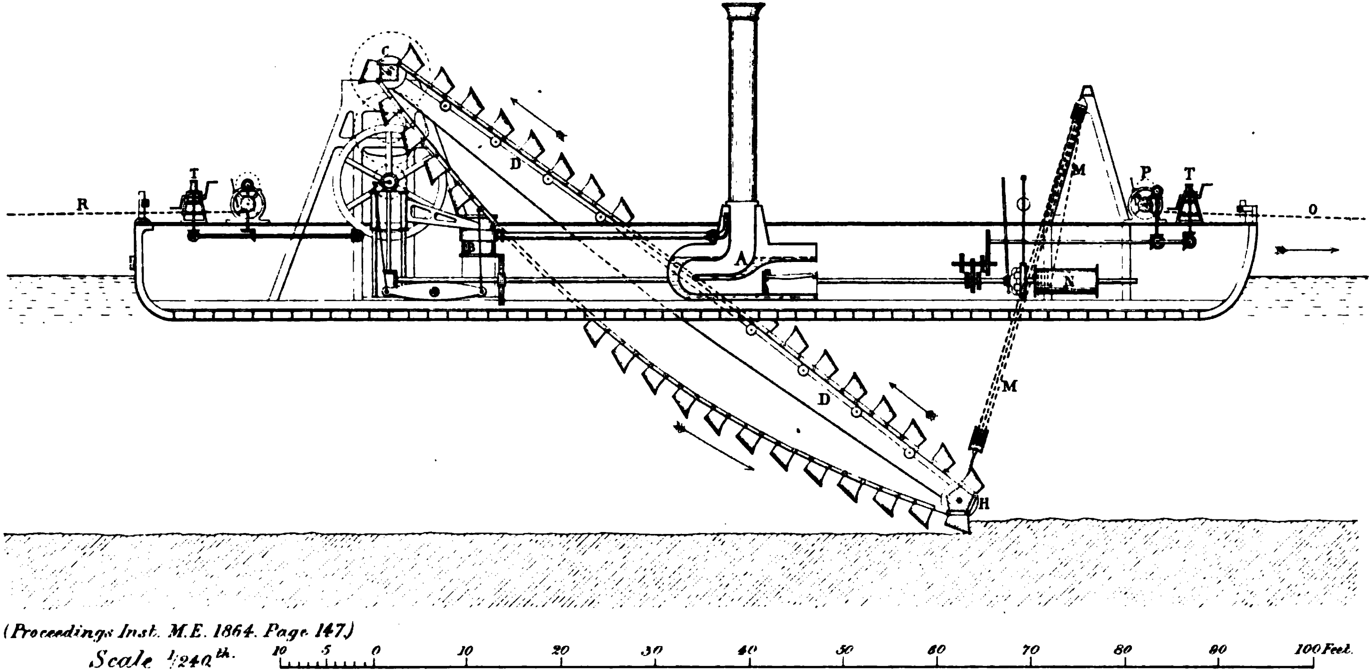
Scale 1/16th



(*Proceedings Inst. M.E. 1864. Page 123*)

CLYDE DREDGERS.

Fig. 1. *Longitudinal Section of Dredger.*

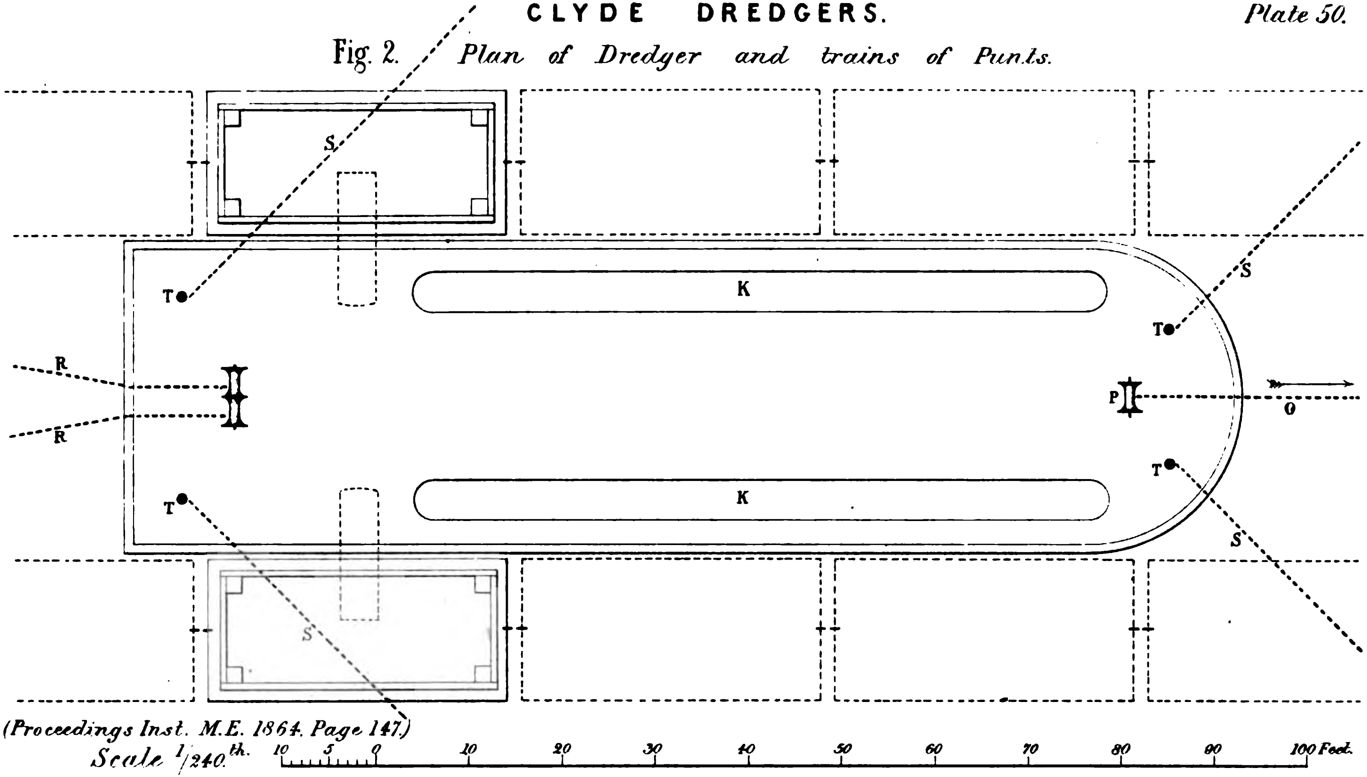


(Proceedings Inst. M.E. 1864. Page 147.)

Scale 1/240th.

CLYDE DREDGERS.

Fig. 2. *Plan of Dredger and trains of Punts.*

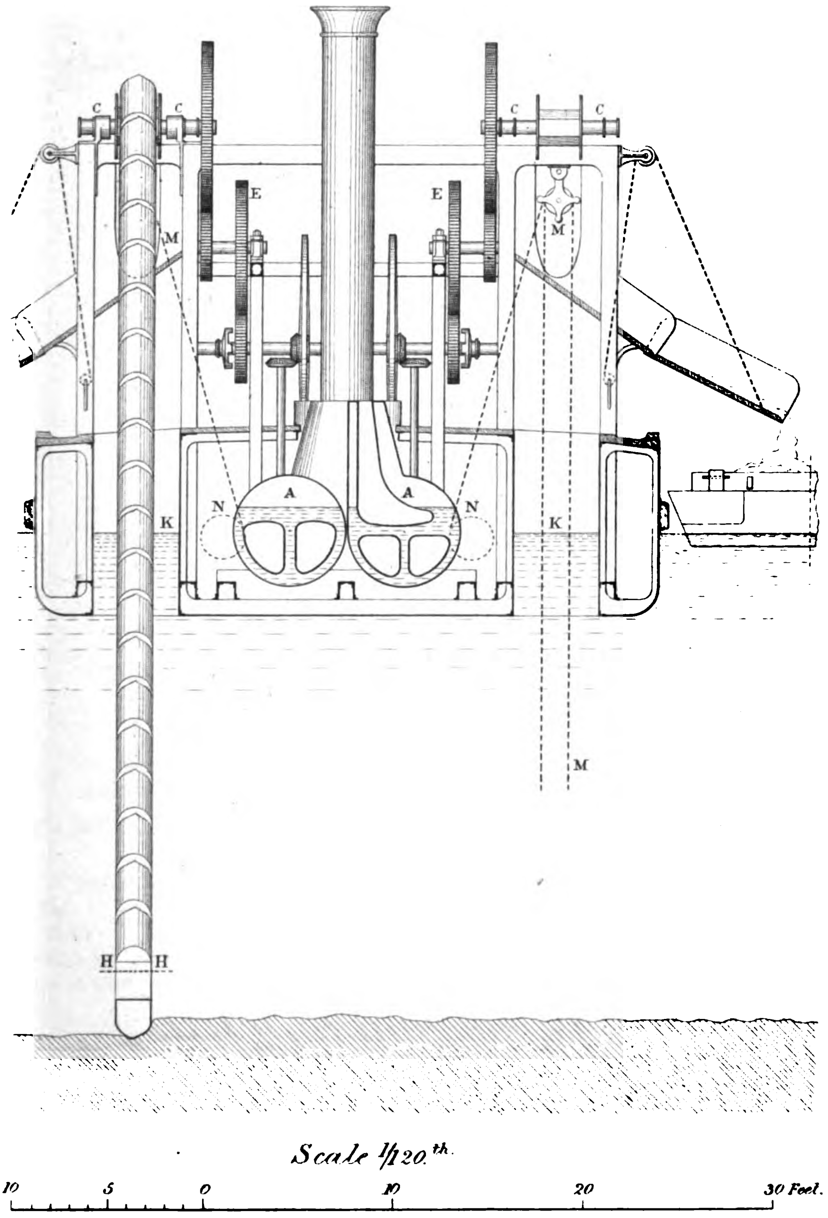


(Proceedings Inst. M.E. 1864. Page 147.)

Scale $1/240^{th}$.

CLYDE DREDGERS.

Fig. 3. *Transverse Section of Dredger.*



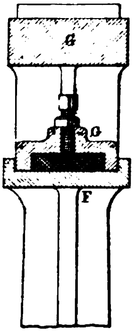
Scale 1/120th.

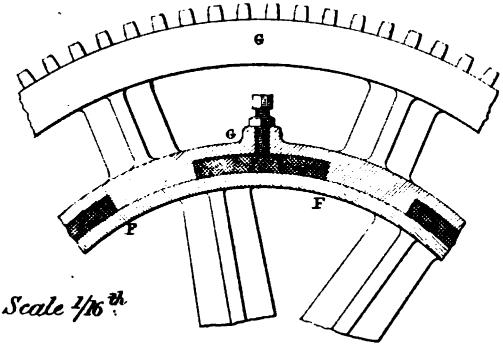
(Proceedings Inst. M.E. 1864. Page 147.)

CLYDE DREDGERS.

Plate 52.

Fig. 4. *Friction Wheel.* Fig. 5.





Scale 1/16th.

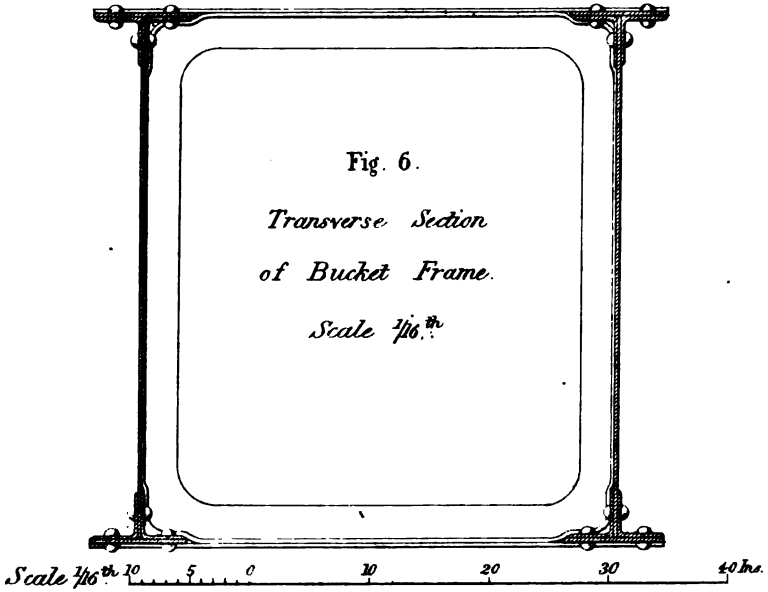


Fig. 6.

Transverse Section of Bucket Frame.

Scale 1/16th.

Diagram showing Deepening of Clyde by Dredging.

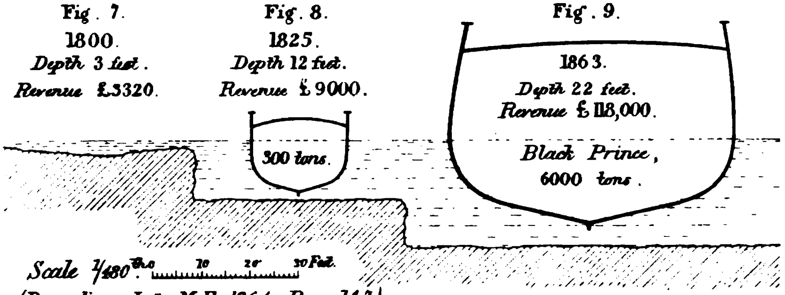


Fig. 7.

1800.

Depth 3 feet.

Revenue £3320.

Fig. 8.

1825.

Depth 12 feet.

Revenue £9000.

300 tons.

Fig. 9.

1863.

Depth 22 feet.

Revenue £118,000.

Black Prince, 6000 *tons.*

(Proceedings Inst. M.E. 1864. Page 147.)

CLYDE DREDGERS.

Plate 53.

Dredger Buckets.

Fig. 10. *Vertical Section of Bucket.*

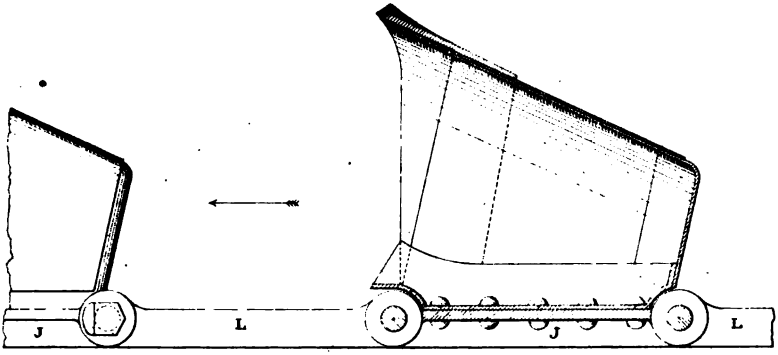


Fig. 11. *Plan of Back of Bucket.*

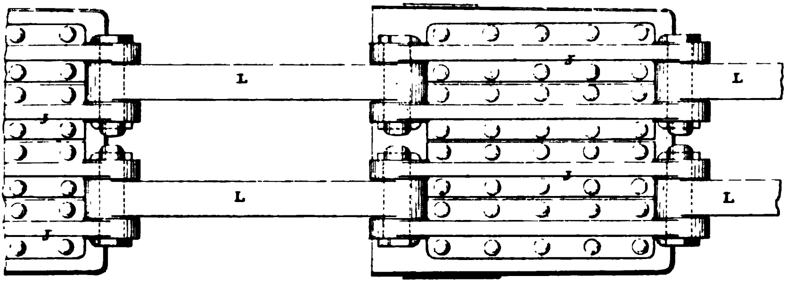


Fig. 12. *Transverse Section at Mouth of Bucket.*

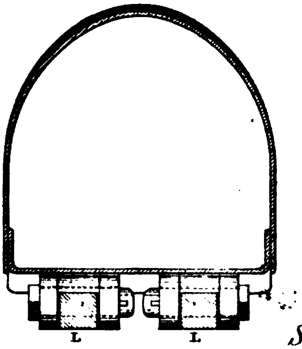
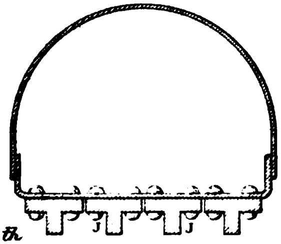


Fig. 13.

Transverse Section at Bottom of Bucket.

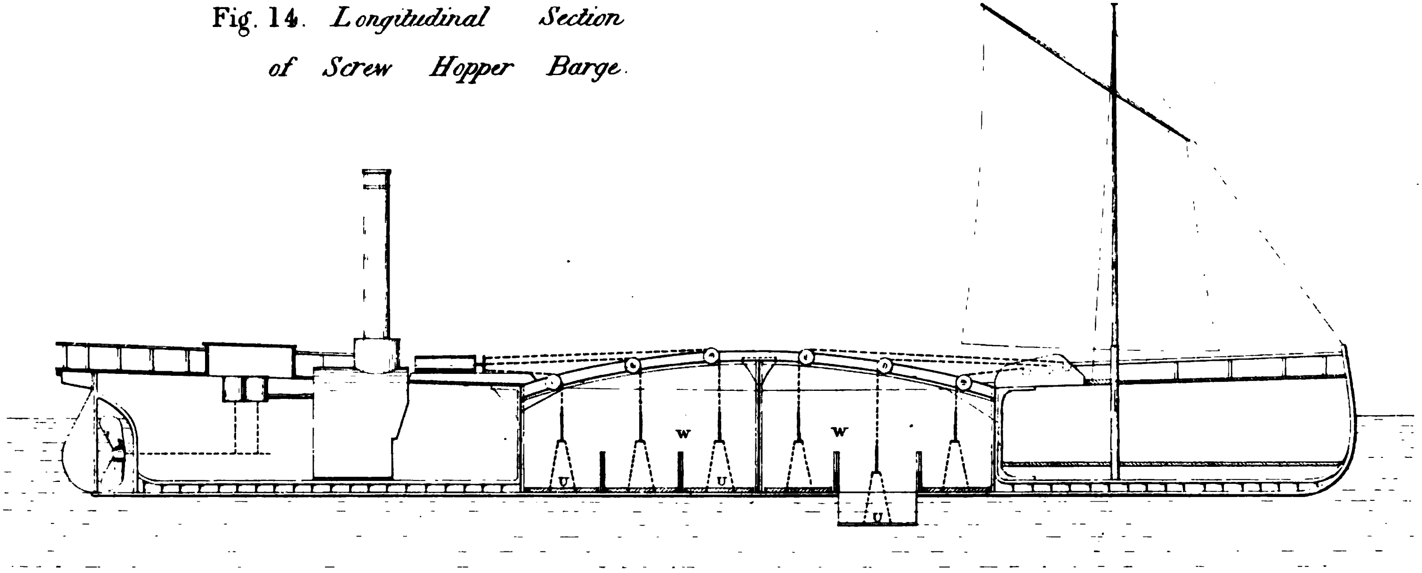


Scale 1/16th.

(*Proceedings Inst. M.E. 1864. Page 147.*)

CLYDE DREDGERS.

Fig. 14. *Longitudinal Section of Screw Hopper Barge.*

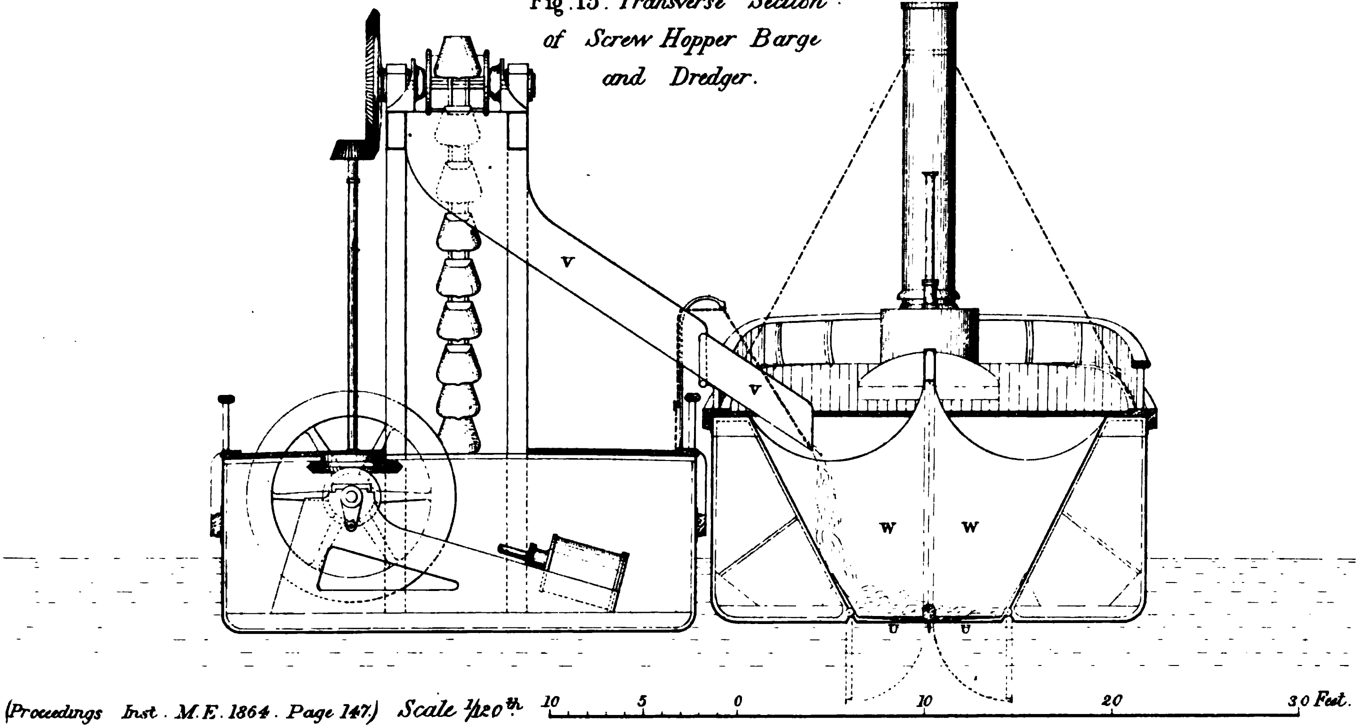


(*Proceedings Inst. M.E 1864. Page 147*)

Scale 1/240th

CLYDE DREDGERS.

Fig. 15. *Transverse Section of Screw Hopper Barge and Dredger.*

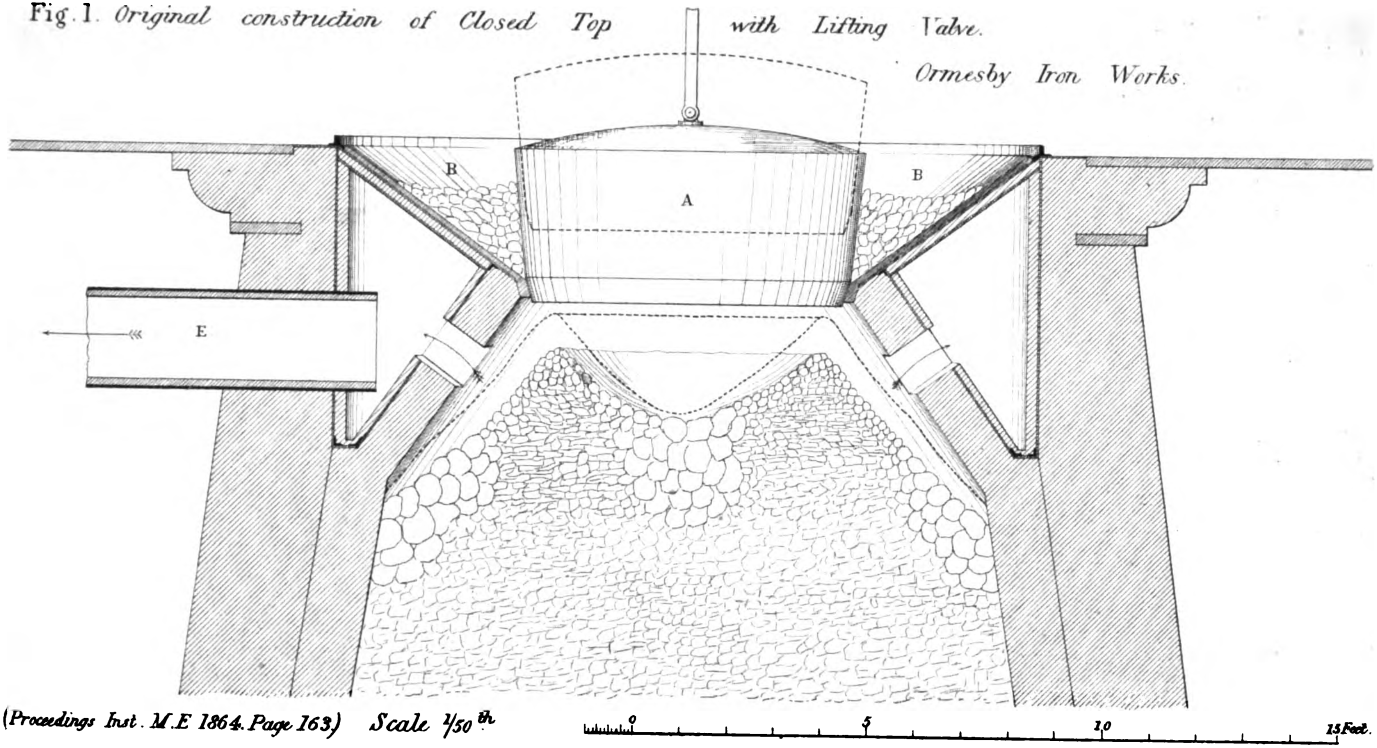


(Proceedings Inst. M.E. 1864. Page 147.) *Scale 1/120th.*

BLAST FURNACES.

Fig. 1. *Original construction of Closed Top with Lifting Valve.*

Ormesby Iron Works.



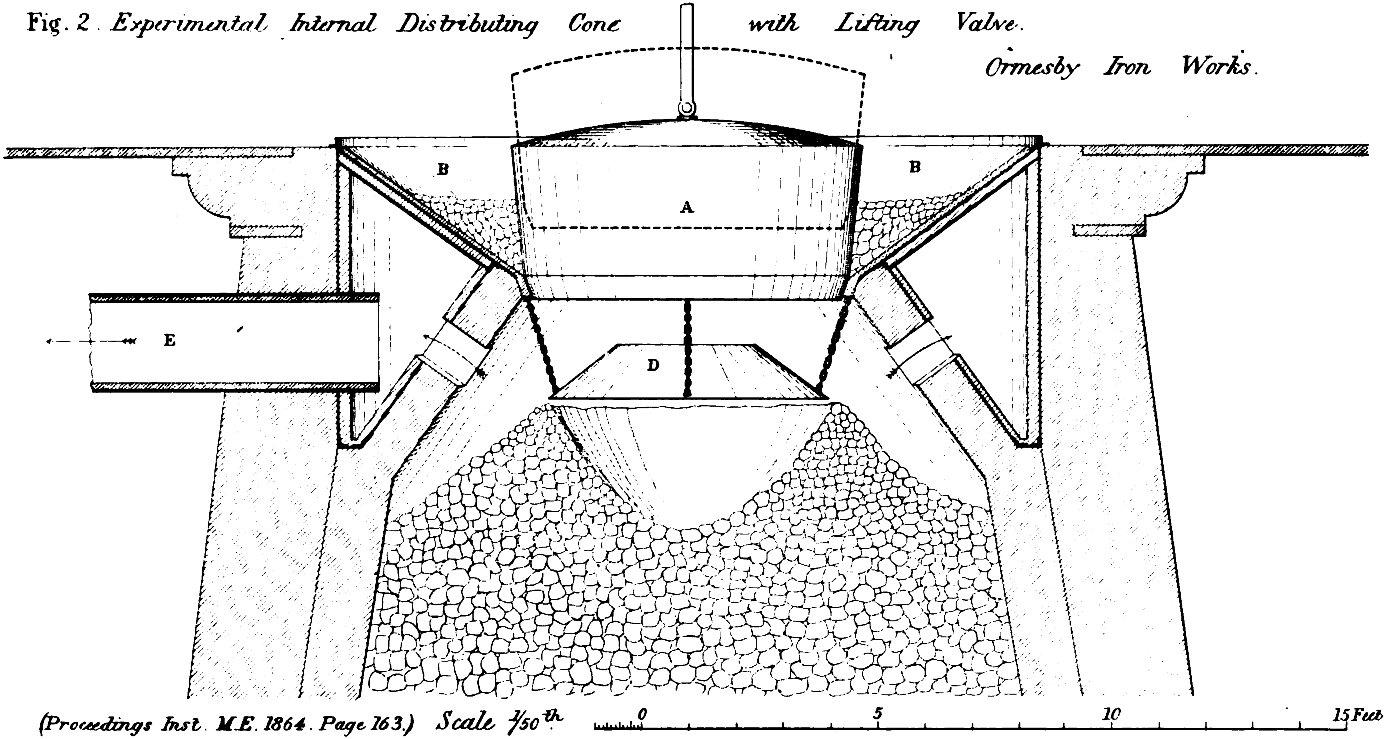
Scale 1/50th

(Proceedings Inst. M.E. 1864. Page 163)

BLAST FURNACES.

Fig. 2. *Experimental Internal Distributing Cone with Lifting Valve.*

Ormesby Iron Works.



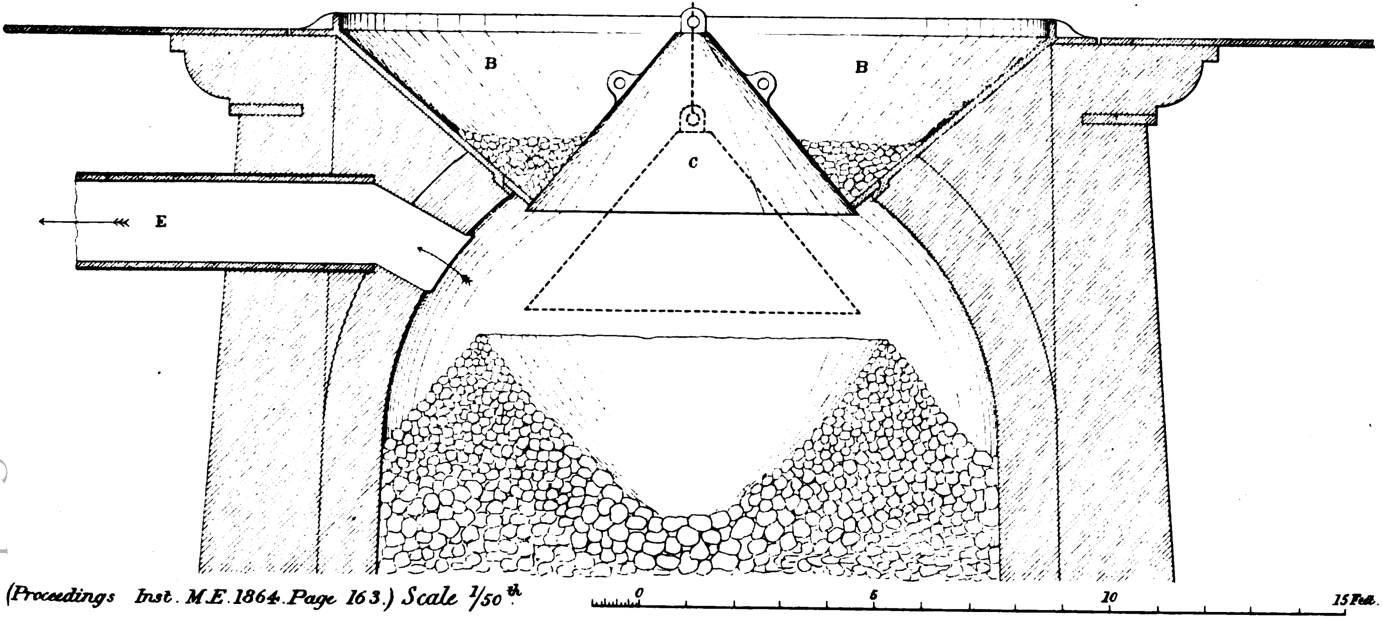
(Proceedings Inst. M.E. 1864. Page 163.) *Scale 1/50th.*

Plate 58.

BLAST FURNACES.

Fig. 3. *Ordinary construction of Closed Top with Lowering Cone Valve.*

Final arrangement at Ormesby Iron Works.



(Proceedings Inst. M.E. 1864. Page 163.) Scale 1/50th.

HEAVY ENGINEERING TOOLS.

Fig. 1. *Long Double Lathe for turning long shafts or screws.*

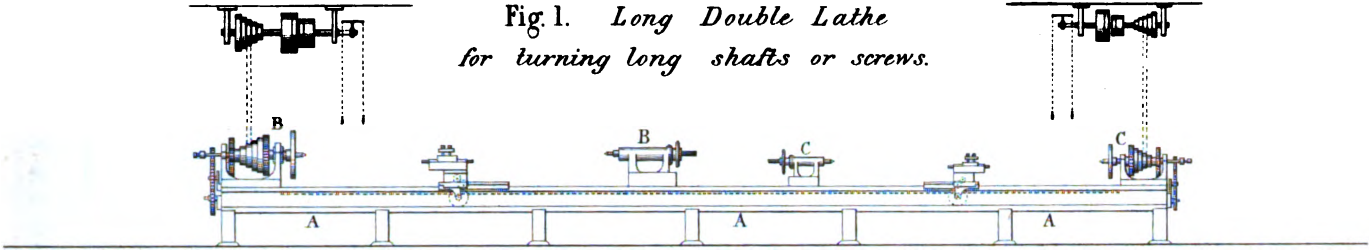
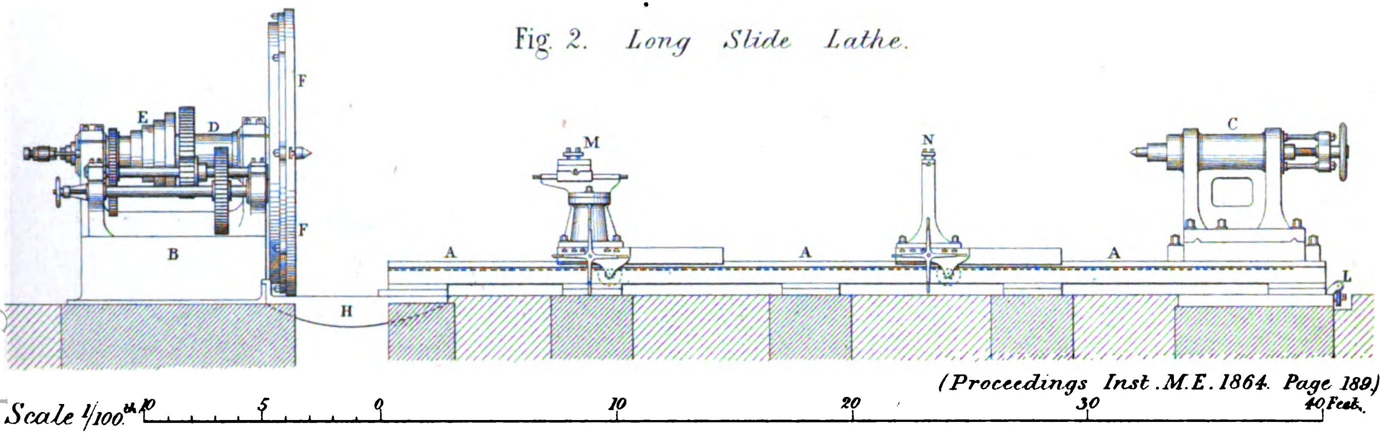


Fig. 2. *Long Slide Lathe.*



(Proceedings Inst. M.E. 1864. Page 189.)

Long Slide Lathe.

Fig. 3. *End Elevation.*

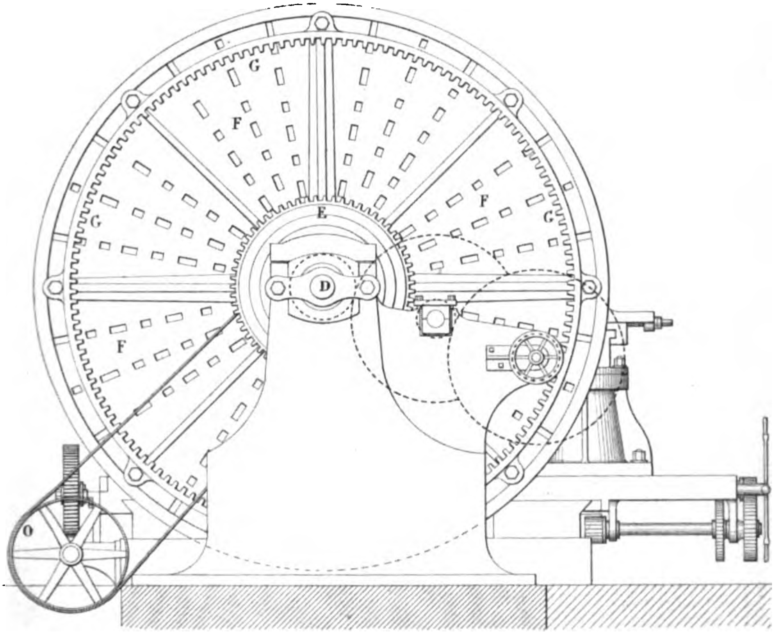
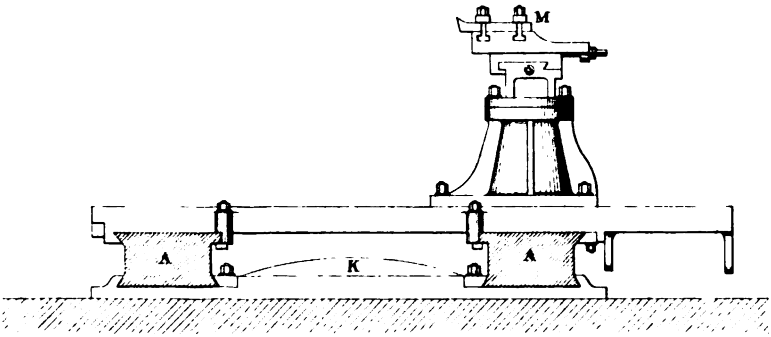
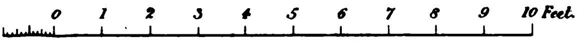


Fig. 4. *Transverse Section.*





Scale 1/50th.

(Proceedings Inst. M.E. 1864. Page 189.)

Fig. 5. V Groove of Planing Machine.
Scale 1/4th.

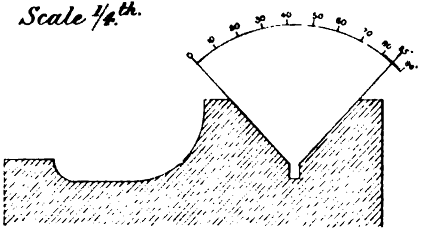
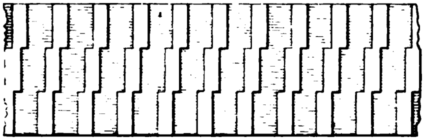
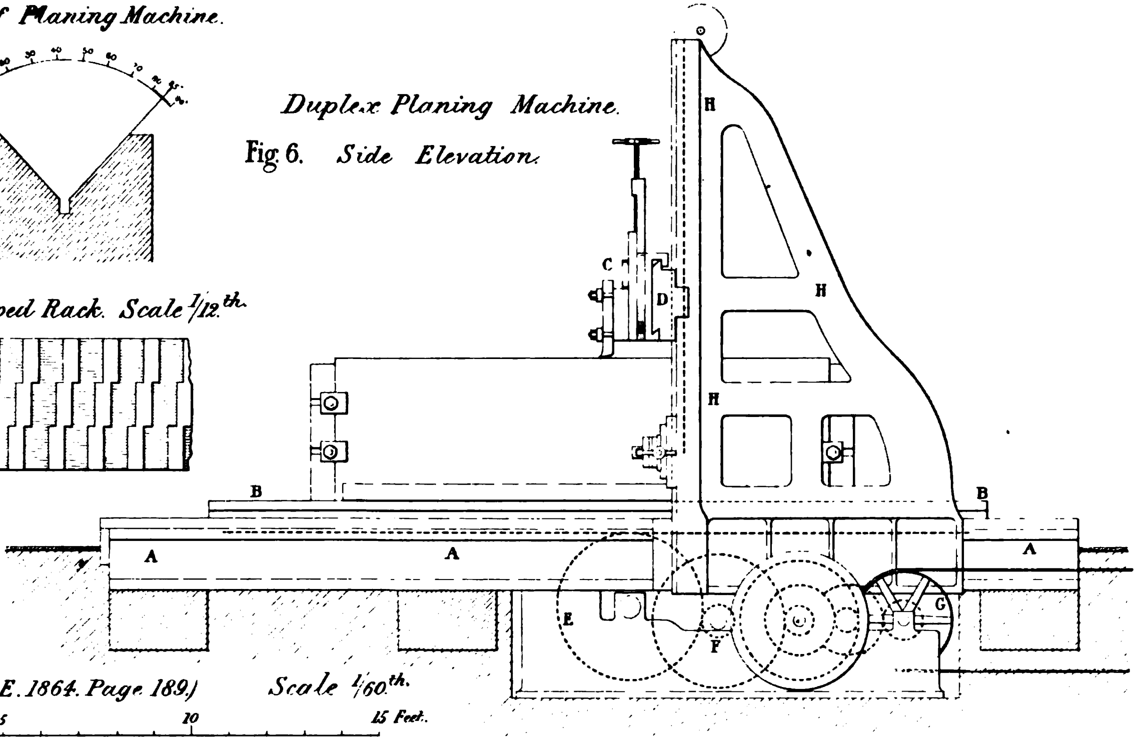


Fig. 7. Plan of Stepped Rack. Scale 1/12th.



Duplex Planing Machine.

Fig. 6. Side Elevation.



(Proceedings Inst. M.E. 1864. Page 189.)

Scale 1/60th.

0 5 10 15 Feet.

Duplex Planing Machine.

Fig. 8. *Front Elevation.*

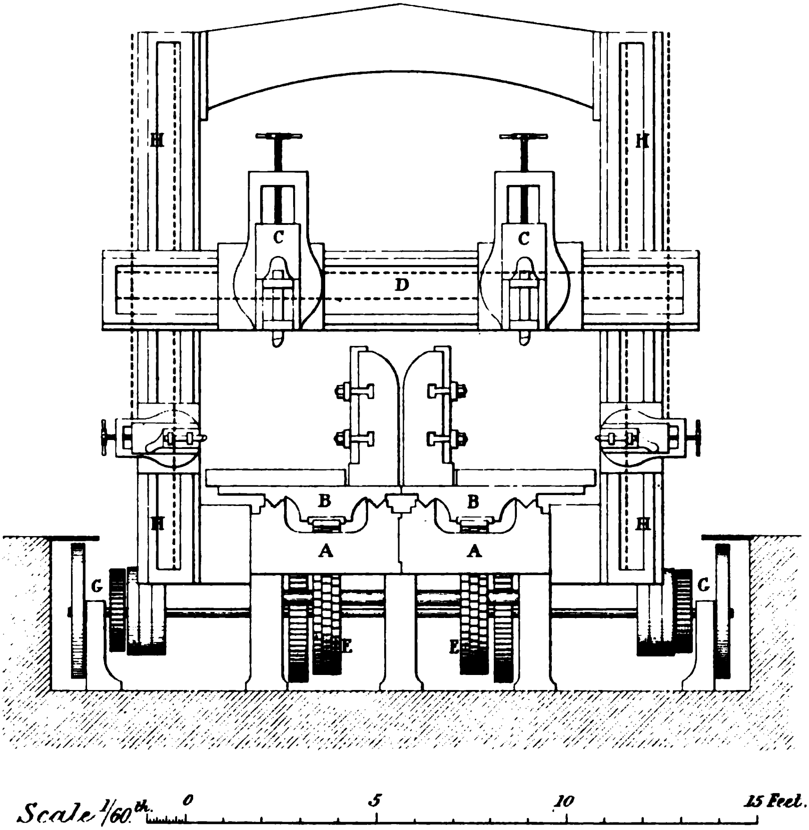
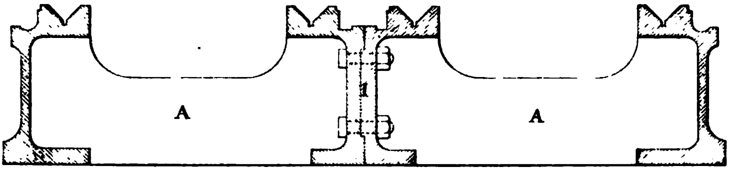


Fig. 9. *Transverse Section of Bed, enlarged.*



Scale 1/24th.

(Proceedings Inst. M.E. 1864. Page 189.)

HEAVY ENGINEERING TOOLS.

Plate 63.

Double Lever Punching, Shearing, and Angle Iron Cutting Machine.

Fig. 10. *Side Elevation.*

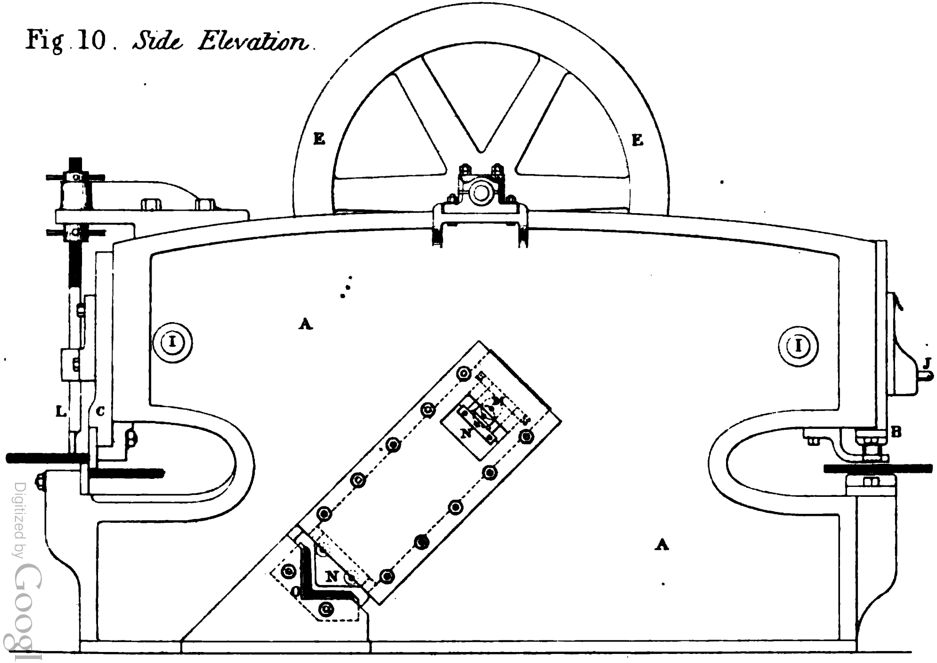
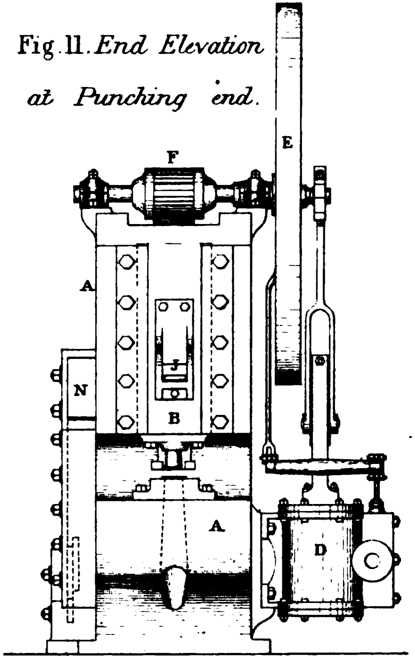


Fig. 11. *End Elevation at Punching end.*



(Proceedings Inst. M.E. 1864. Page 189.)

Scale 2/16th.

10 5 0 10 20 30 40 50 Inches.

HEAVY ENGINEERING TOOLS.

Plate 64.

Double Lever Punching, Shearing, and Angle Iron Cutting Machine.

Fig. 13. Shears. Scale 1/8th.

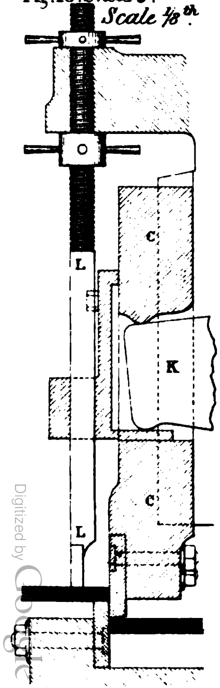


Fig. 12. Longitudinal Section. Scale 1/16th.

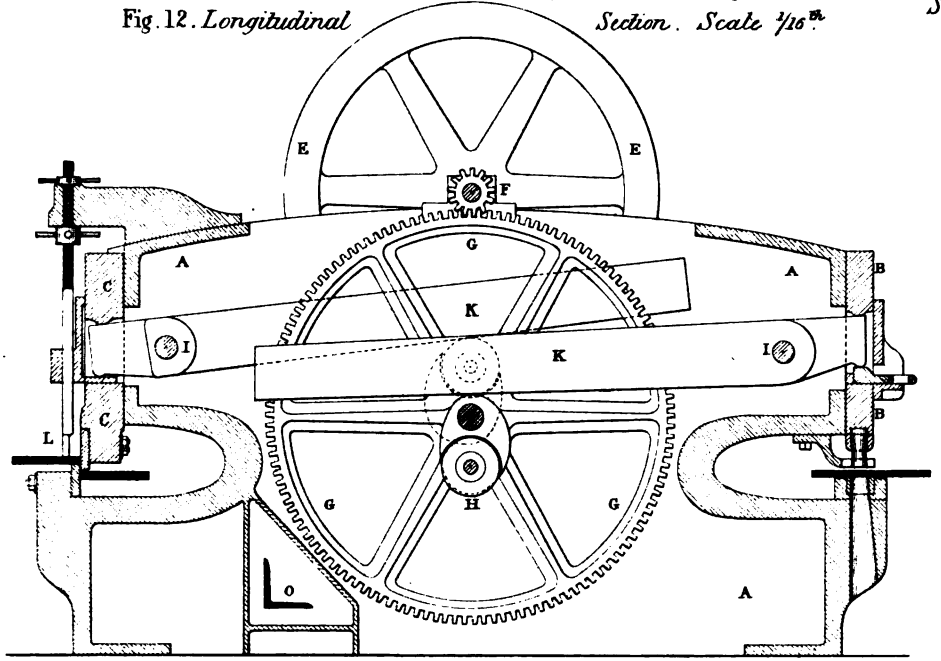
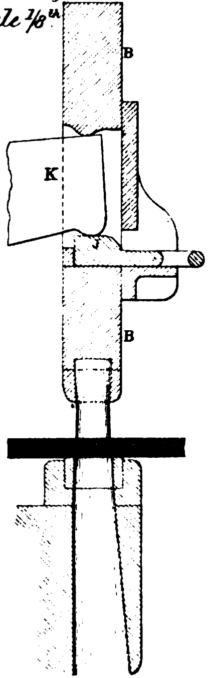


Fig. 14. Punch. Scale 1/8th.



(Proceedings Inst. M.E. 1864. Page 189.)

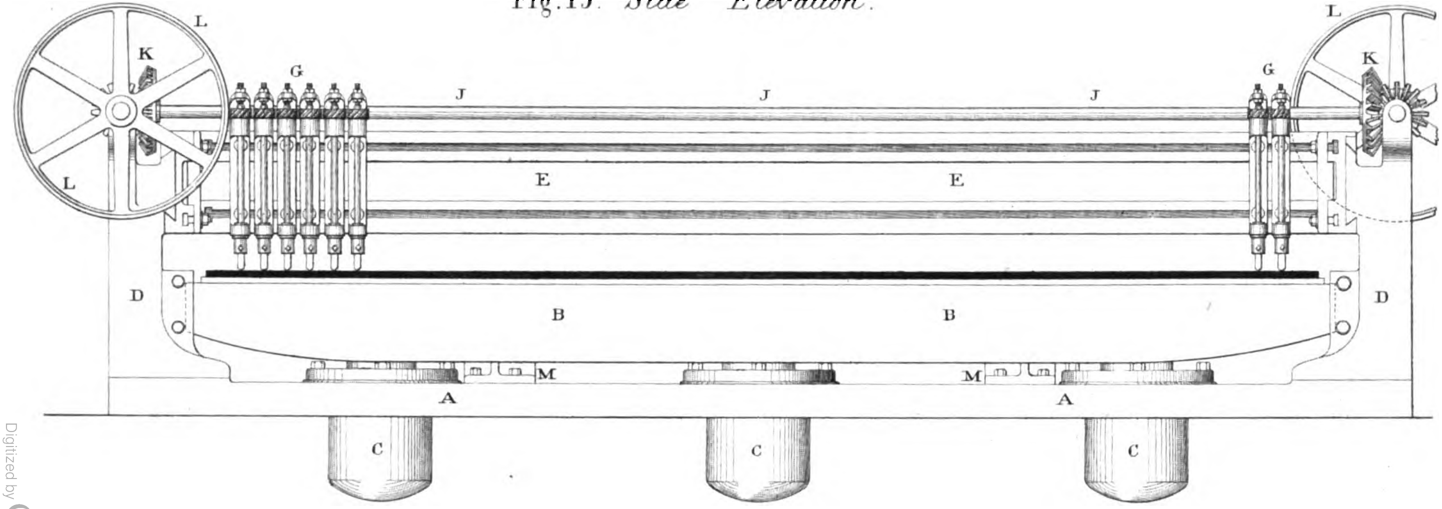
Scale 1/16th

10 5 0 10 20 30 40 50 Inches.

HEAVY ENGINEERING TOOLS.

Multiple Drilling Machine.

Fig. 15. *Side Elevation.*

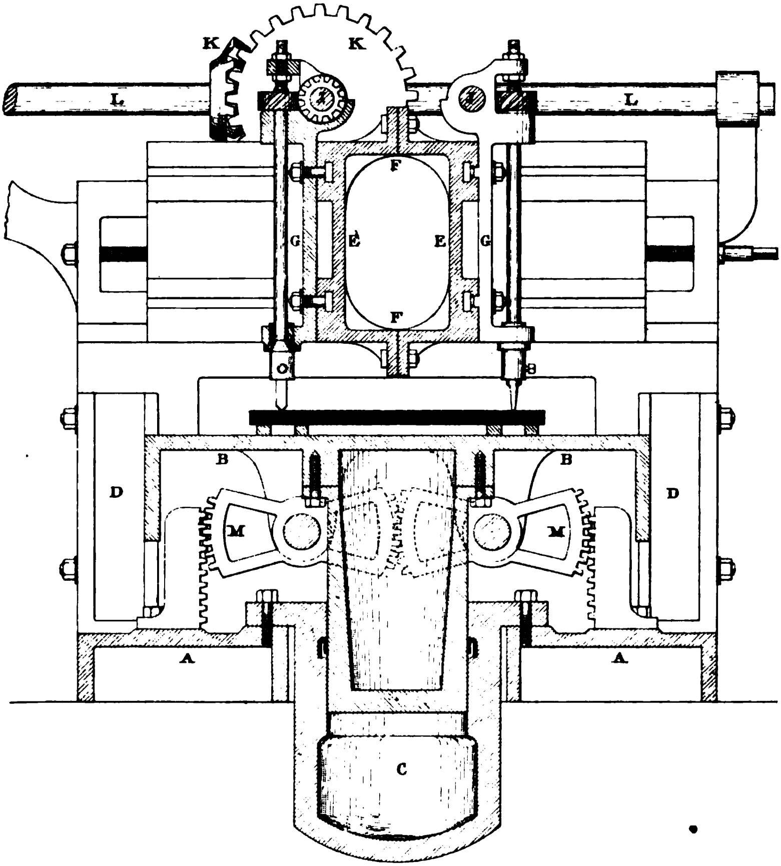


Scale $^1/_{32^{nd}}$ 0 5 10 15 *Feet.*

(Proceedings Inst. M.E. 1864. Page 189.)

Multiple Drilling Machine.

Fig. 16. *Transverse Section, enlarged.*



Scale 1/16th.

10 5 0 10 20 30 40 50 Inches.

(Proceedings Inst. M.E. 1864. Page 189)

HEAVY ENGINEERING TOOLS.

Plate 67.

Multiple Drilling Machine. *Details of Drill Spindles &c. and Drills.*

Fig. 17

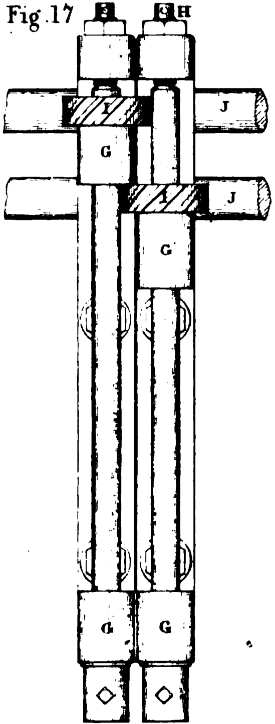


Fig. 18

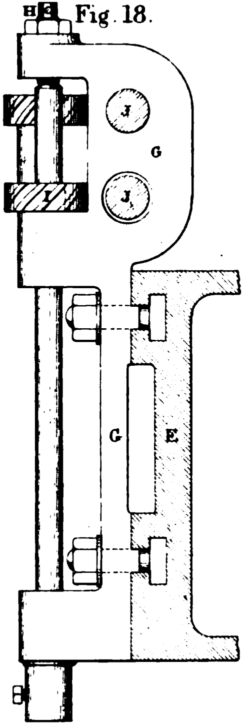


Fig. 19

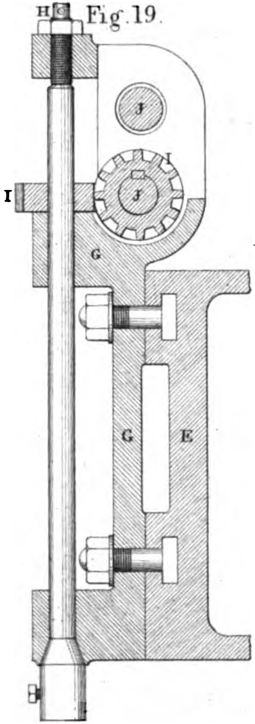


Fig. 20

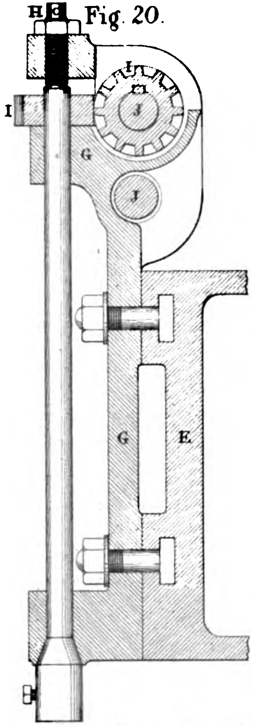


Fig. 21

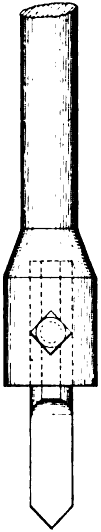
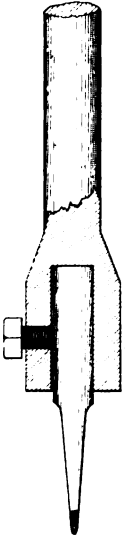


Fig. 22



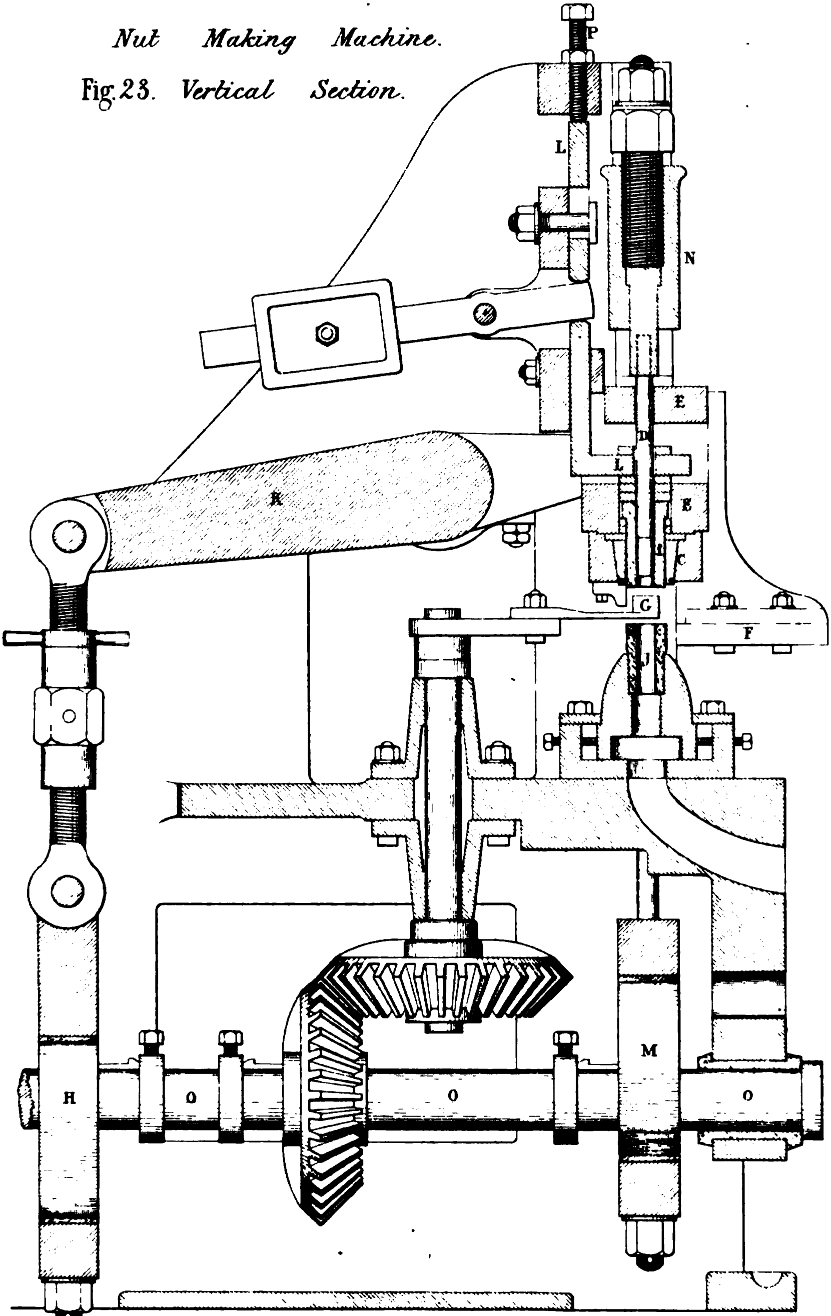
Scale 1/4th.

Scale 1/8th. 0 10 20 30 Inches.

(Proceedings Inst. M.E. 1864. Page 189.)

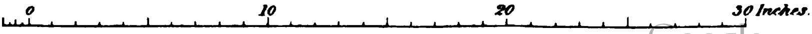
Nut Making Machine.

Fig. 23. *Vertical Section.*



(Proceedings Inst. M.E. 1864. Page 189)

Scale 1/8th.

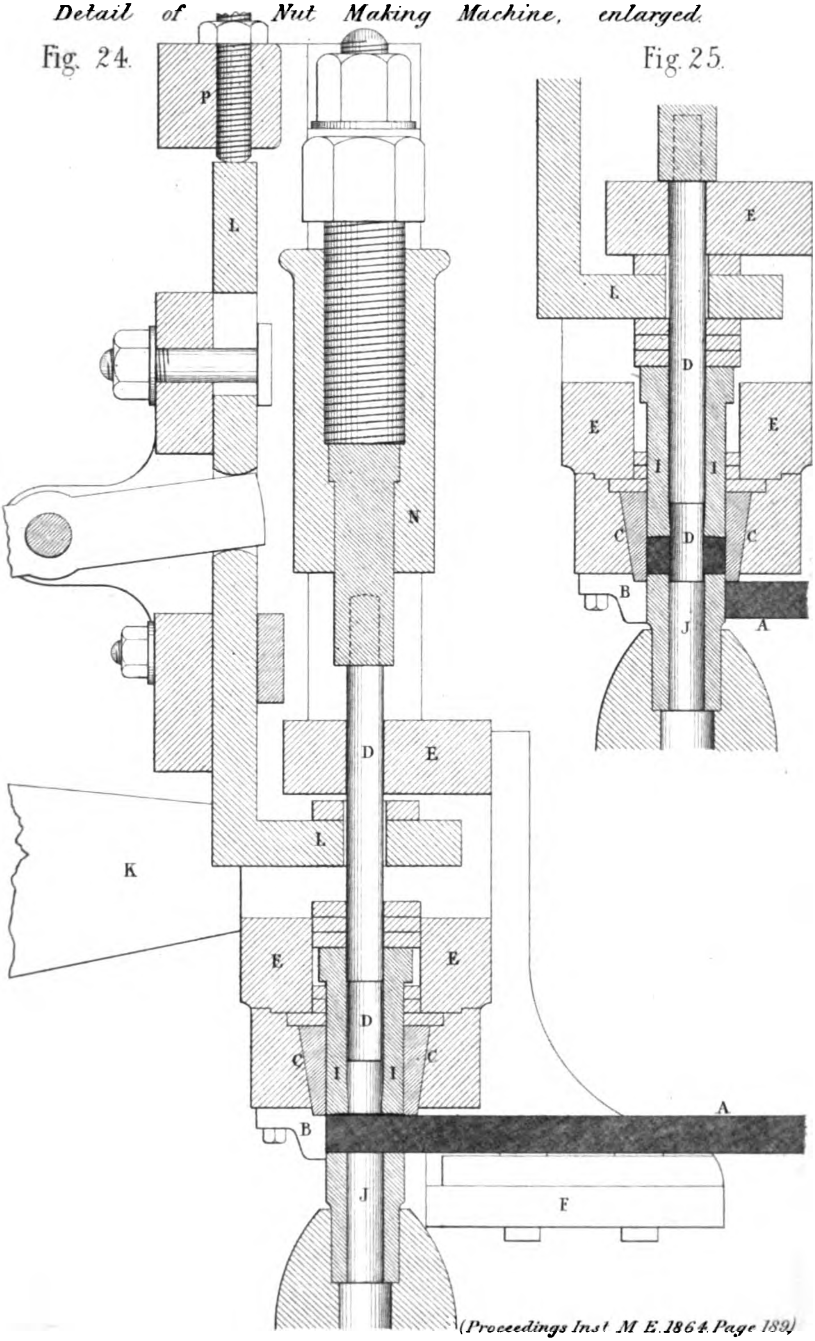


HEAVY ENGINEERING TOOLS. *Plate 69.*

Detail of Nut Making Machine, enlarged.

Fig. 24.

Fig. 25.



(Proceedings Inst M E. 1864. Page 189)

Scale 1/4th. 0 5 *10 Inches.*

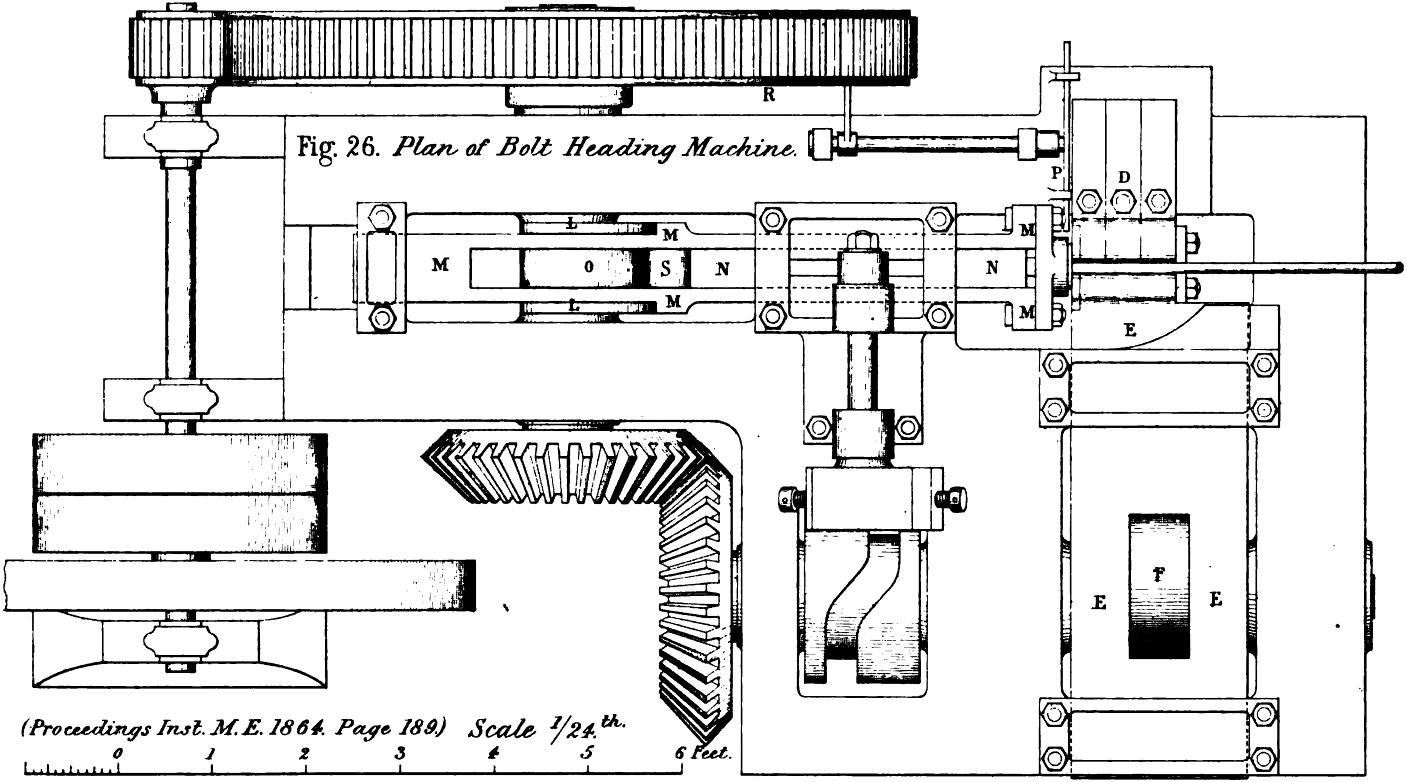
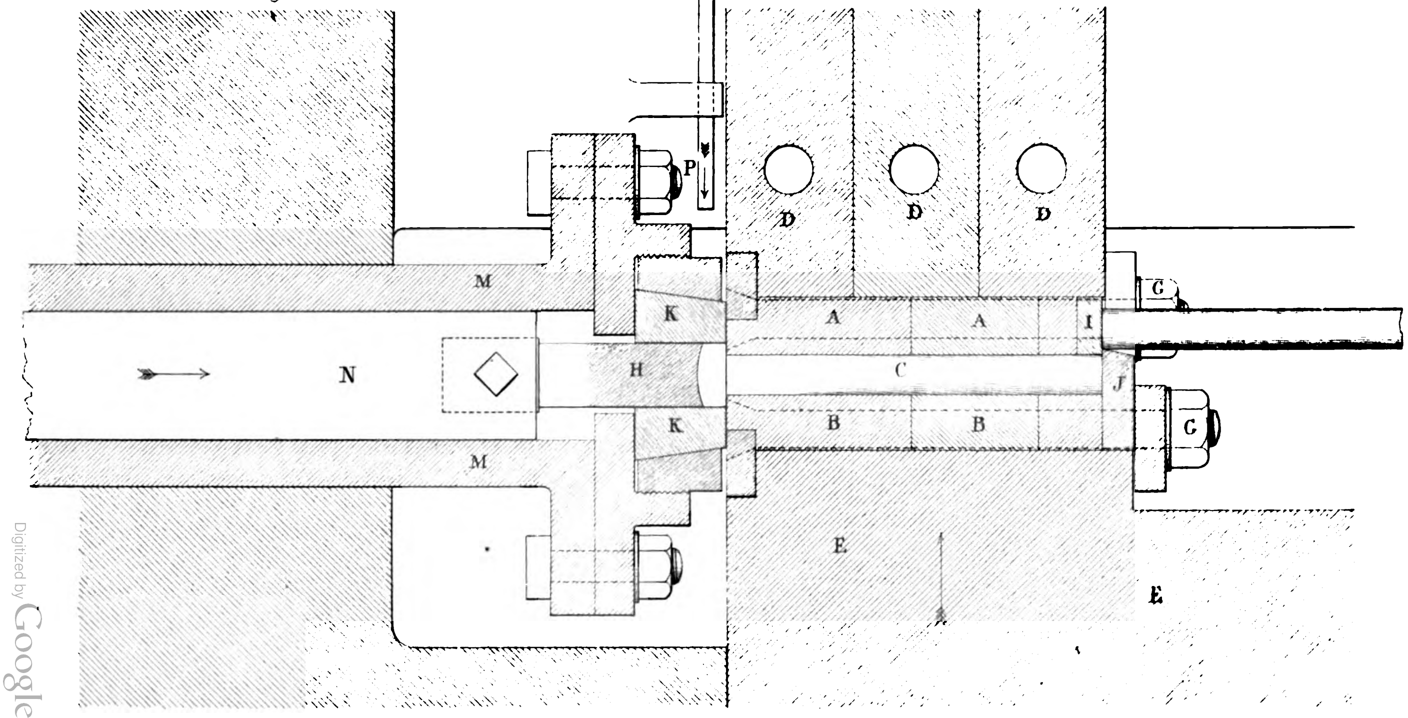


Fig. 26. *Plan of Bolt Heading Machine.*

(Proceedings Inst. M.E. 1864. Page 189) *Scale 1/24.th.*

HEAVY ENGINEERING TOOLS.

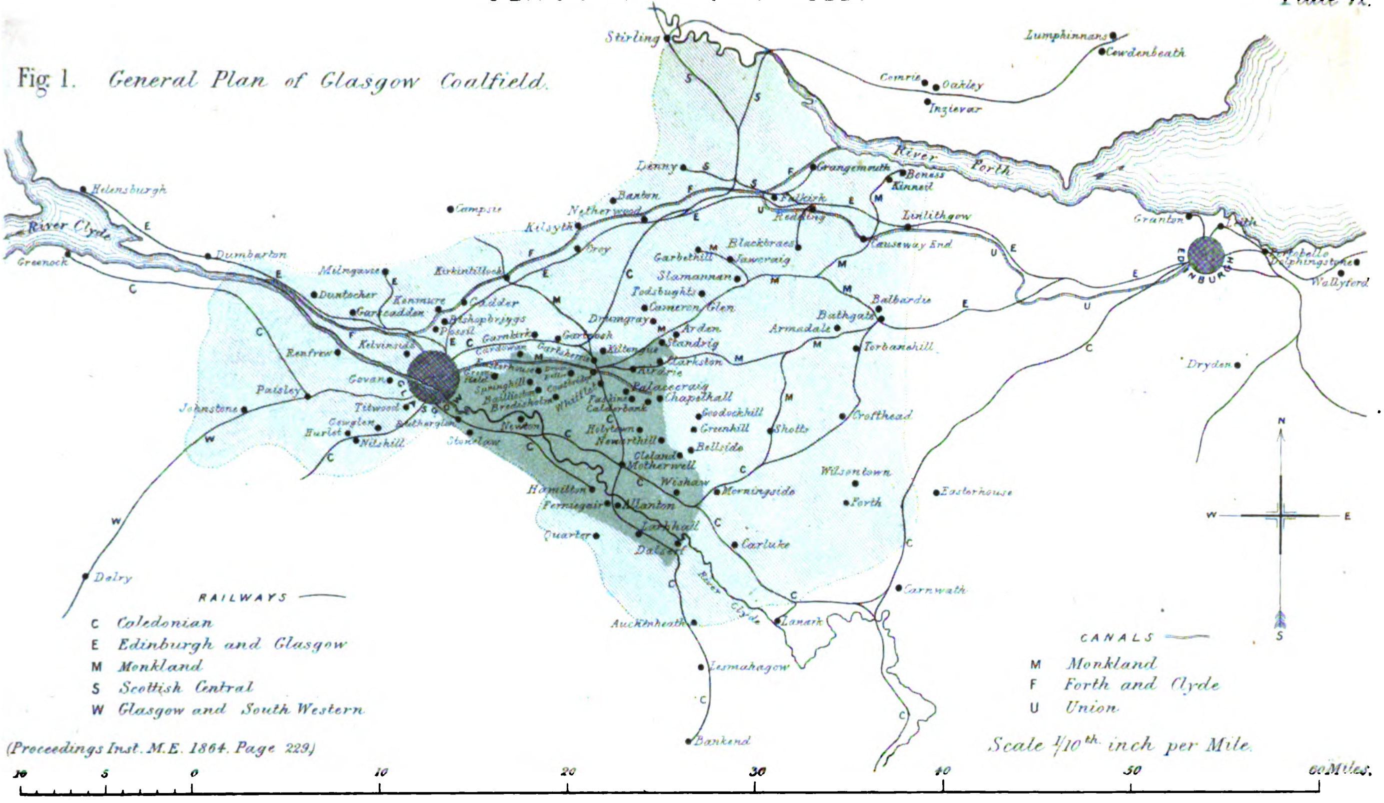
Fig. 27. *Sectional Plan enlarged of Bolt Heading Machine.*



(Proceedings Inst. M.E. 1864. Page 189) *Scale $^1/_6$th.* 0 5 10 15 20 Inches.

GLASGOW COALFIELD.

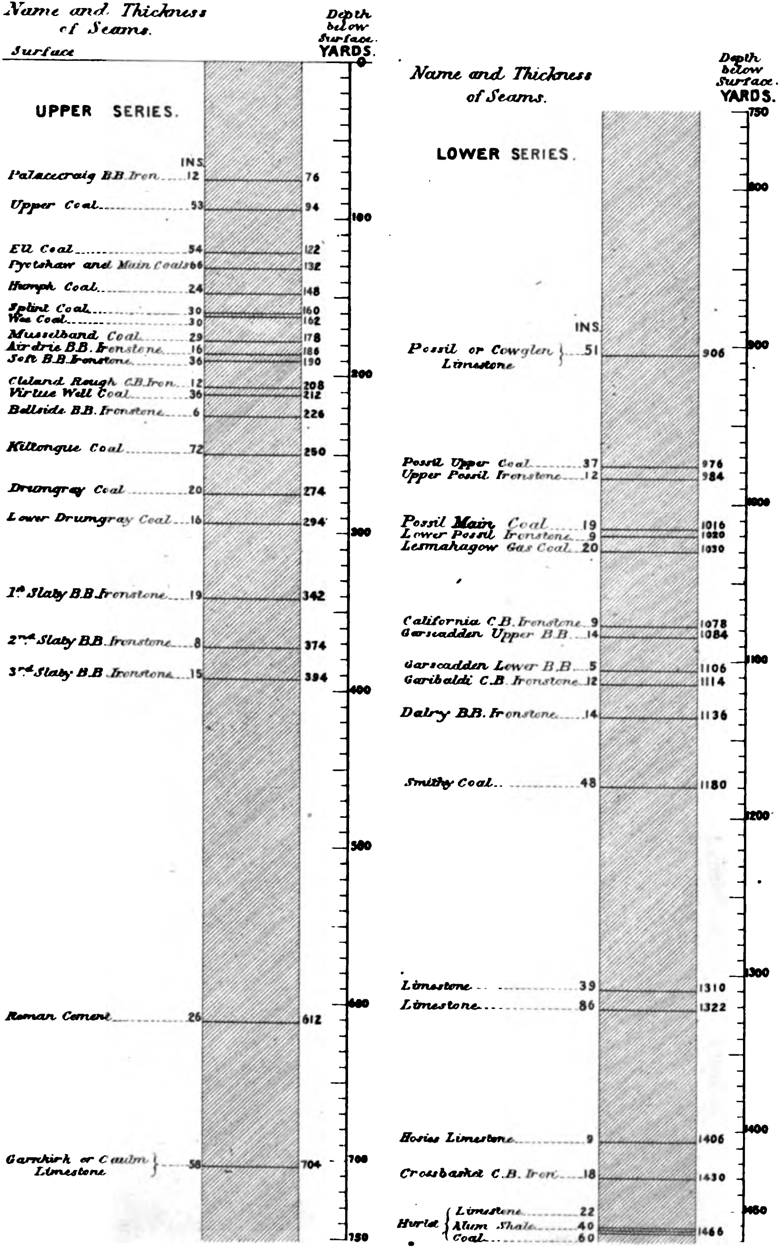
Fig. 1. *General Plan of Glasgow Coalfield.*



(Proceedings Inst. M.E. 1864. Page 229.)

GLASGOW COALFIELD.

Fig. 2. General average Section of Strata.


Name and Thickness of Seams.
Depth below Surface. YARDS.
Surface
0
UPPER SERIES.
INS.
Palacecraig B.B. Iron ..... 12 — 76
Upper Coal ..... 53 — 94
100
Ell Coal ..... 54 — 122
Pyotshaw and Main Coals 66 — 132
Humph Coal ..... 24 — 148
Splint Coal ..... 30 — 160
Wee Coal ..... 30 — 162
Musselband Coal ..... 29 — 178
Airdrie B.B. Ironstone ..... 16 — 186
Soft B.B. Ironstone ..... 36 — 190
200
Cleland Rough C.B. Iron ..... 12 — 208
Virtue Well Coal ..... 36 — 212
Bellside B.B. Ironstone ..... 6 — 226
Kiltongue Coal ..... 72 — 250
Drumgray Coal ..... 20 — 274
Lower Drumgray Coal ..... 16 — 294
300
1st Slaty B.B. Ironstone ..... 19 — 342
2nd Slaty B.B. Ironstone ..... 8 — 374
3rd Slaty B.B. Ironstone ..... 15 — 394
400
500
600
Roman Cement ..... 26 — 612
Garnkirk or Caulm Limestone ..... 58 — 704
700
750
Name and Thickness of Seams.
Depth below Surface. YARDS.
750
LOWER SERIES.
800
INS.
900
Possil or Cowglen Limestone ..... 51 — 906
Possil Upper Coal ..... 37 — 976
Upper Possil Ironstone ..... 12 — 984
1000
Possil Main Coal ..... 19 — 1016
Lower Possil Ironstone ..... 9 — 1020
Lesmahagow Gas Coal ..... 20 — 1030
California C.B. Ironstone ..... 9 — 1078
Garscadden Upper B.B. ..... 14 — 1084
1100
Garscadden Lower B.B. ..... 5 — 1106
Garibaldi C.B. Ironstone ..... 12 — 1114
Dalry B.B. Ironstone ..... 14 — 1136
Smithy Coal ..... 48 — 1180
1200
1300
Limestone ..... 39 — 1310
Limestone ..... 86 — 1322
1400
Hosies Limestone ..... 9 — 1406
Crossbasket C.B. Iron ..... 18 — 1430
1450
Hurlet { Limestone ..... 22 / Alum Shale ..... 40 / Coal ..... 60 } — 1466

(Proceedings Inst. M.E. 1864. Page 229)

Scale 1/4300th.

Fig. 3. *Plan of Shaft.*

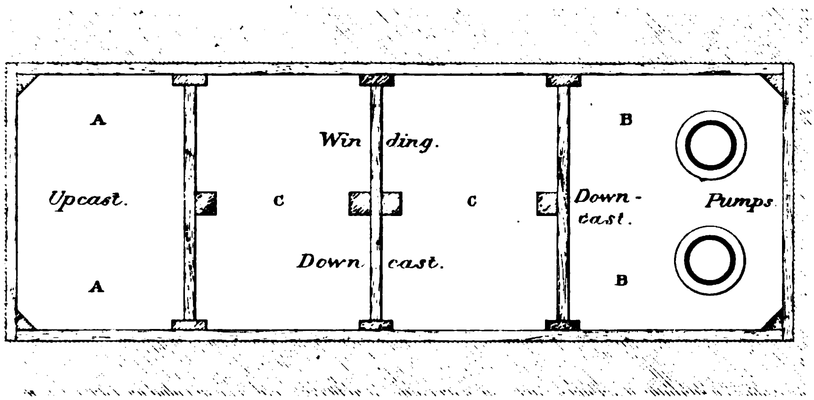
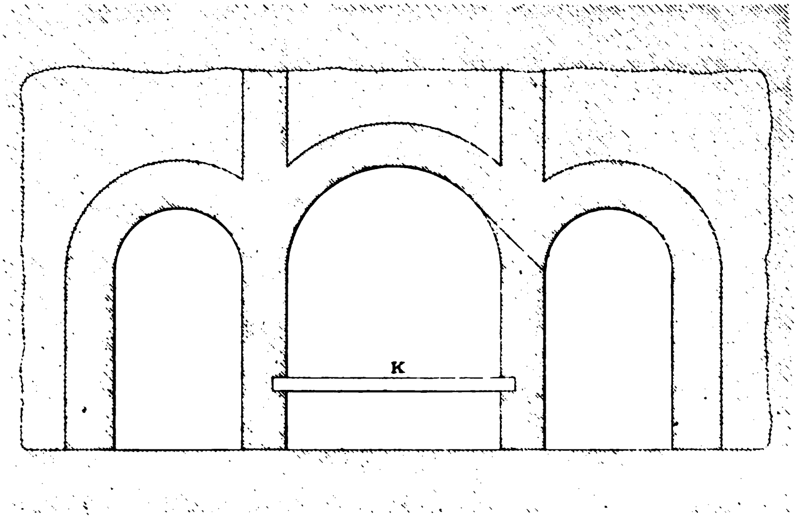


Fig. 4. *Transverse Section of Ventilating Furnace.*

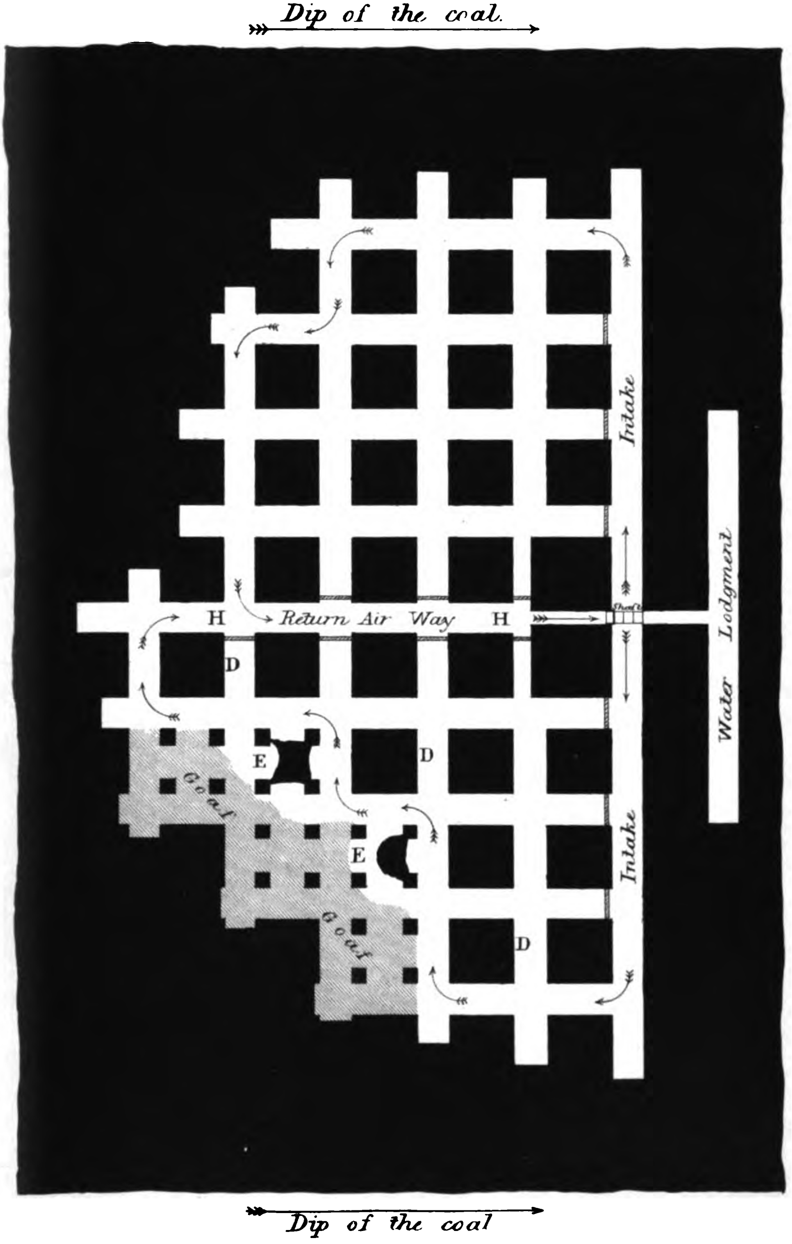


Scale 1/50th

(Proceedings Inst. M. E. 1864. Page 229.)

GLASGOW COALFIELD. *Plate 75.*

Fig. 3. *Plan of Stoop and Room system of working.*

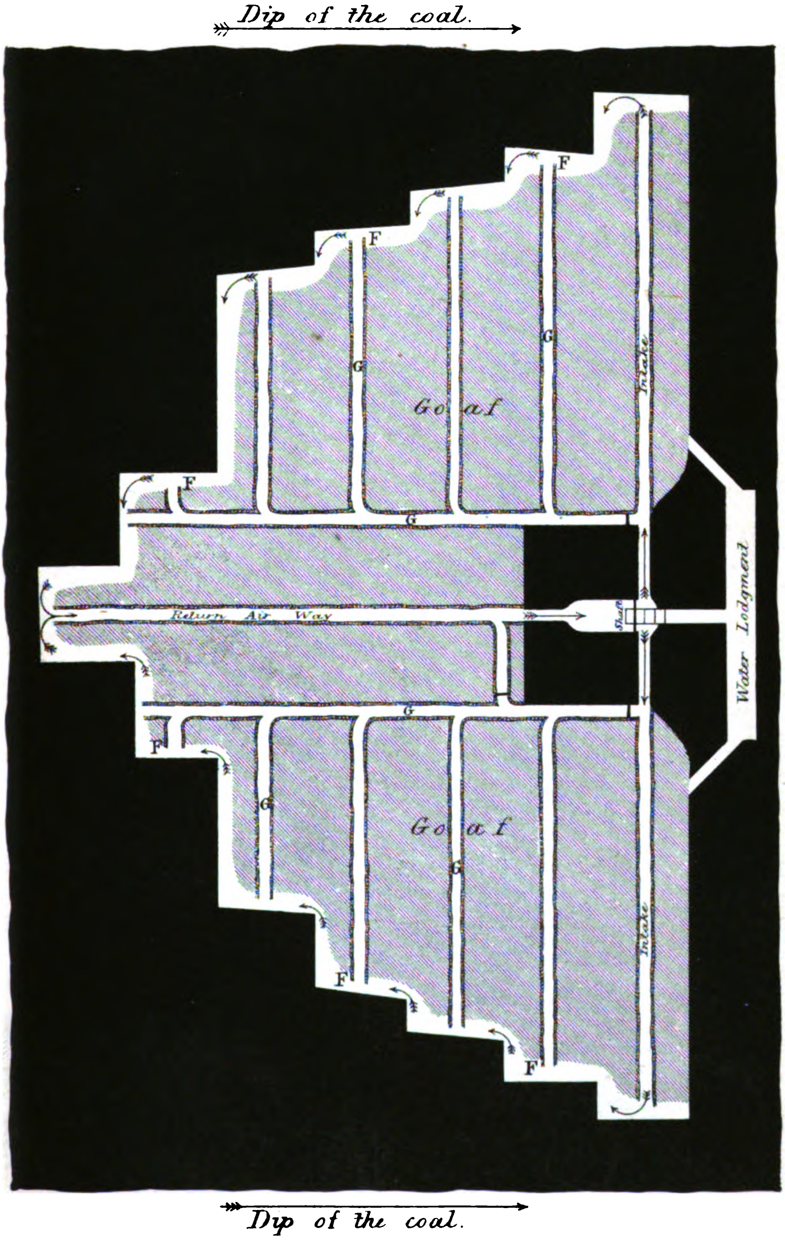


(Proceedings Inst. M.E. 1864. Page 229) *Scale 1/1000th*

0 100 200 300 Feet

GLASGOW COALFIELD. *Plate 76.*

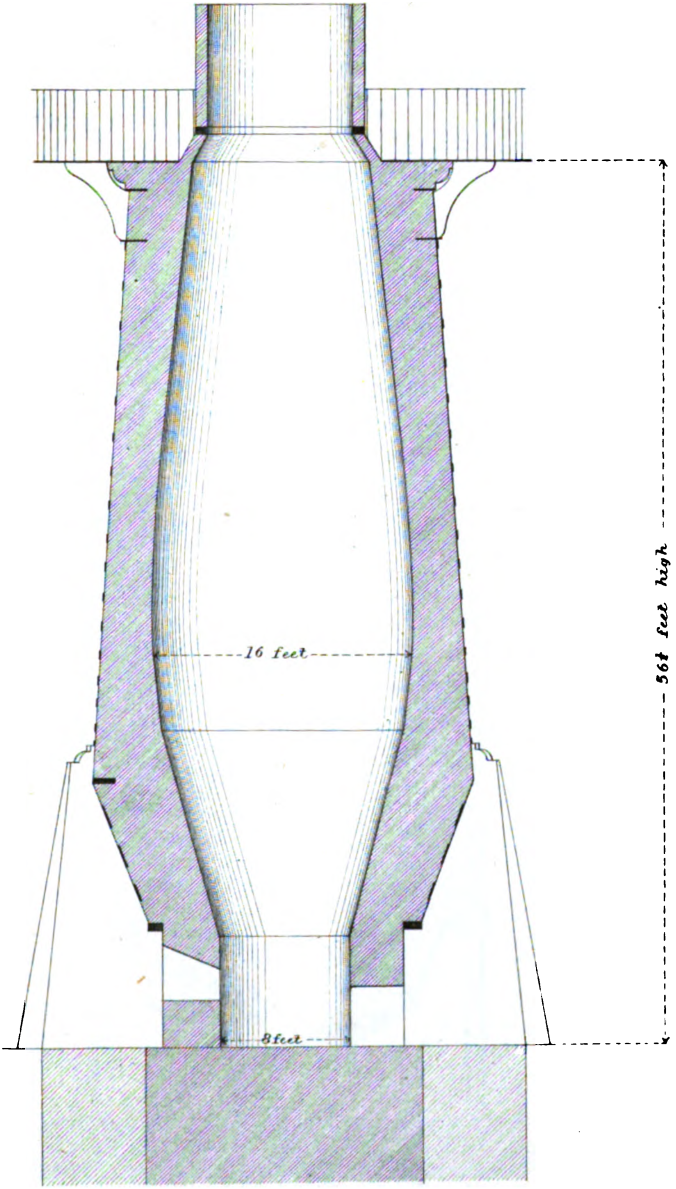
Fig. 6. *Plan of Long Wall system of working.*



(Proceedings Inst. M.E. 1864. Page 229) *Scale 1/1000th.*

0 100 200 300 Feet

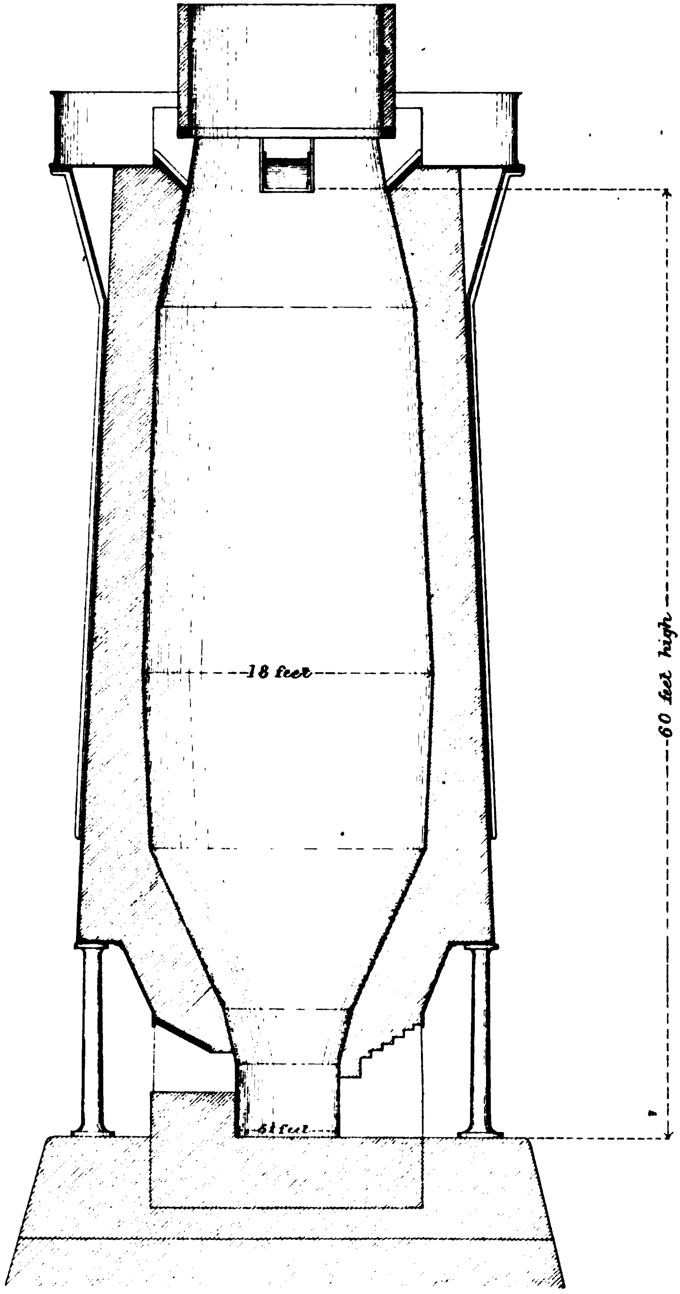
Fig.1. *Ormesby.*



(Proceedings Inst. M.E. 1864. Page 249) *Scale 1/140th*

CLEVELAND BLAST FURNACES. *Plate 78.*

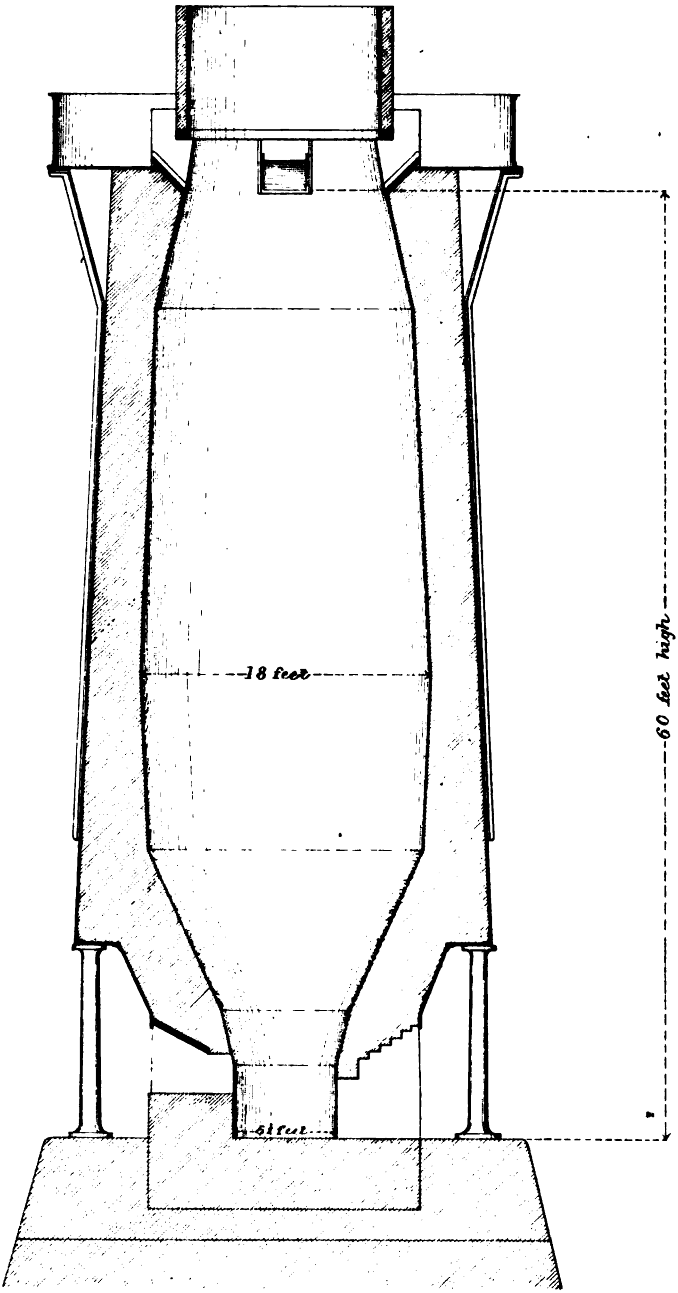
Fig. 2. *Jarrow.*



(Proceedings Inst. M.E. 1864. Page 249) *Scale* $1/140^{th}$

CLEVELAND BLAST FURNACES.. *Plate 78.*

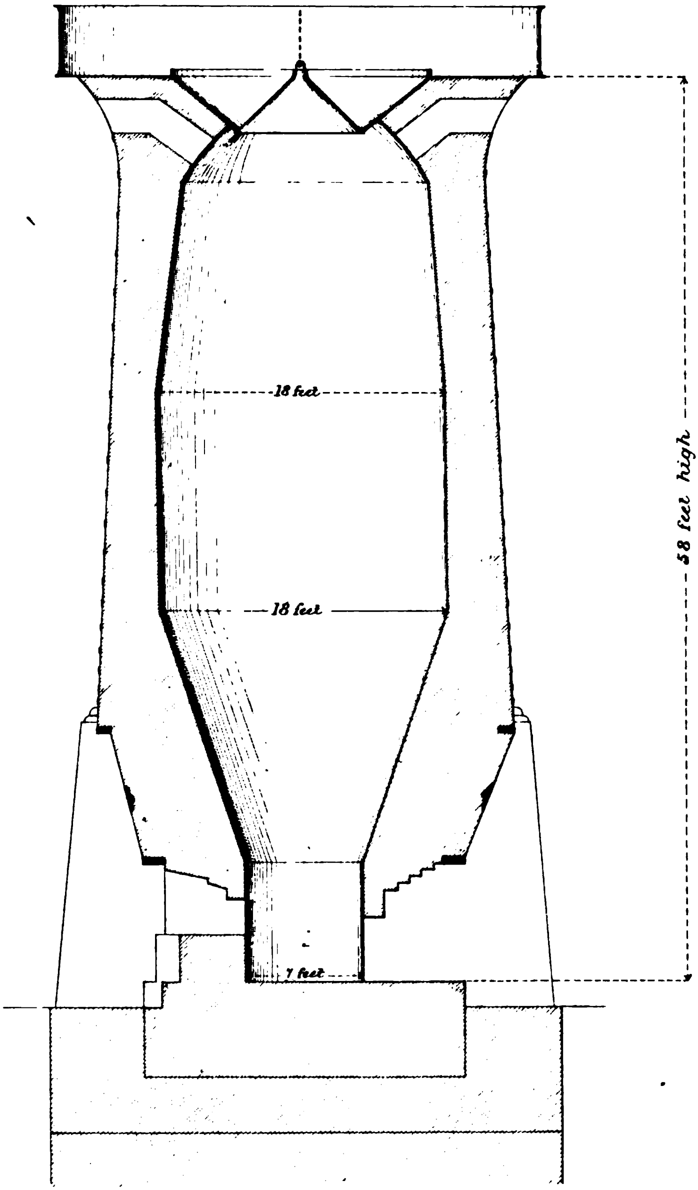
Fig. 2. *Jarrow.*



(Proceedings Inst. M.E. 1864. Page 249.) *Scale 1/140th*

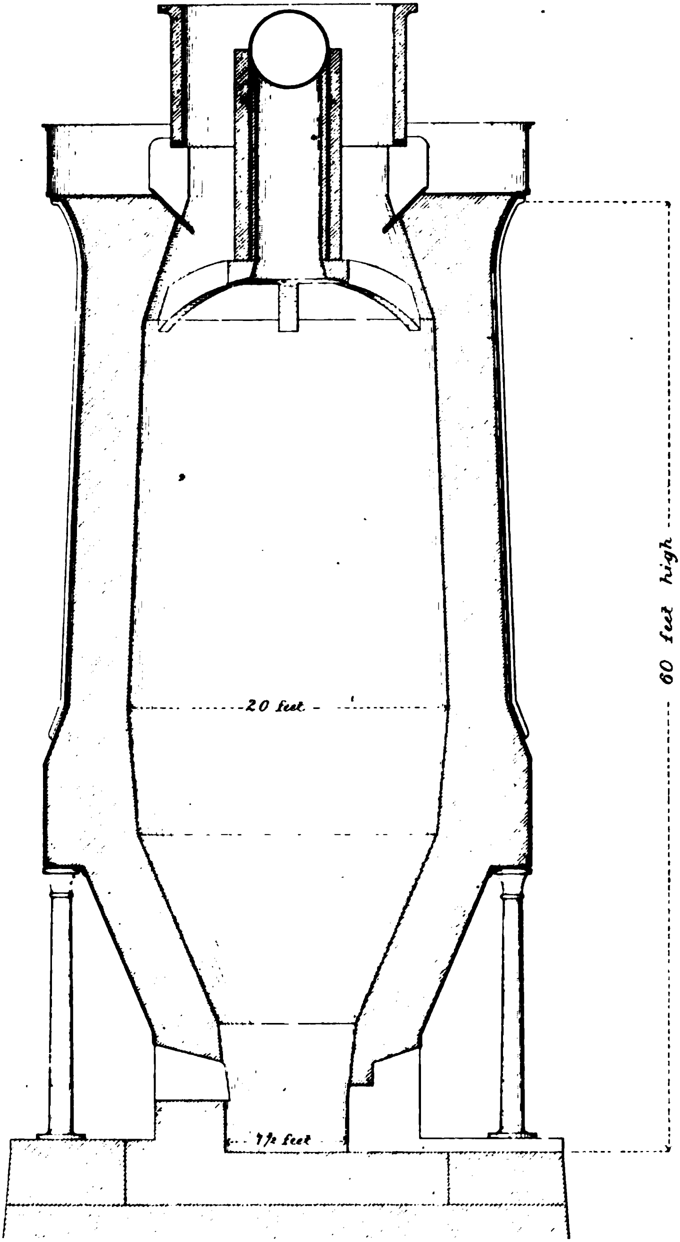
10 5 0 10 20 30 *Feet.*

Fig. 3. *Normanby*.



(Proceedings Inst. M.E. 1864. Page 249.) *Scale* 1/140th

Fig. 4. *Thornaby.*

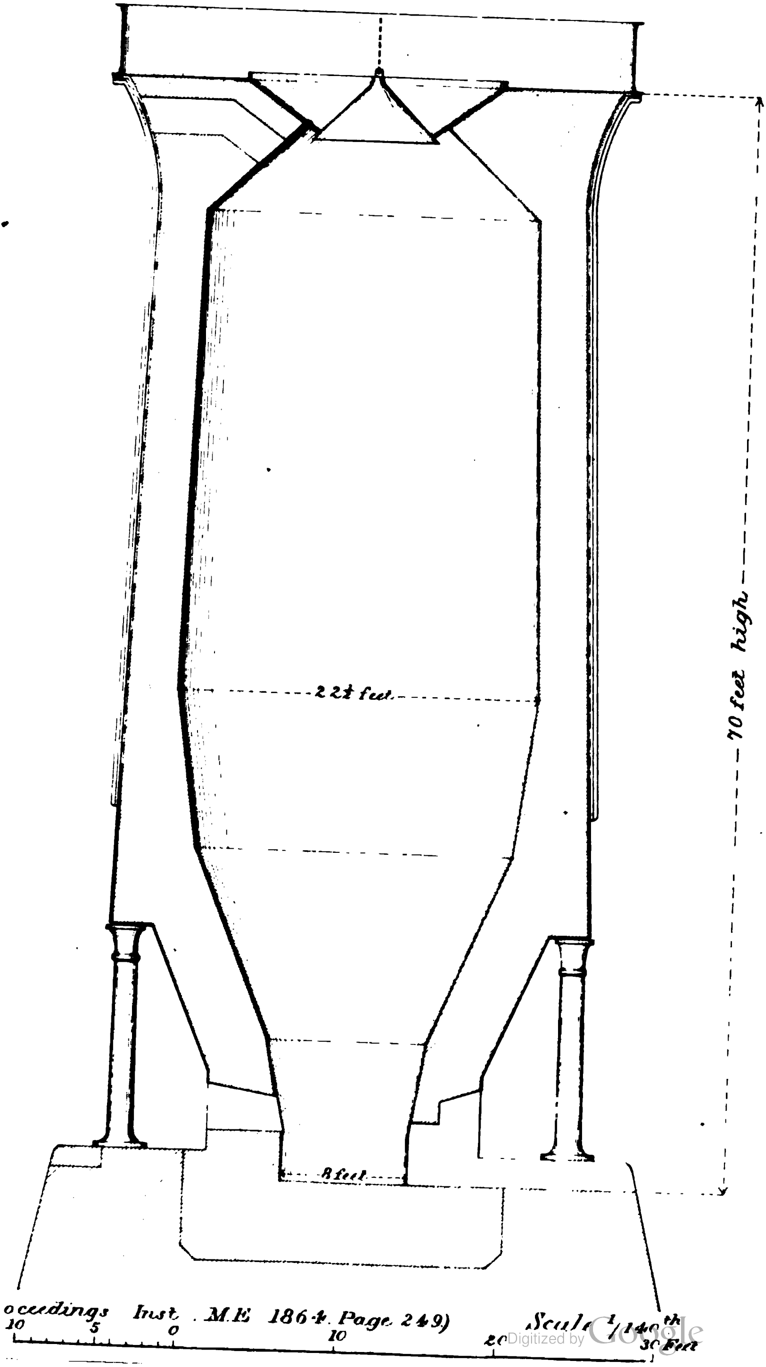


Proceedings Inst. M.E. 1864. Page 249.) *Scale 1/140th.*

10 5 0 10 20 30 Feet

CLEVELAND BLAST FURNACES. *Plate 81.*

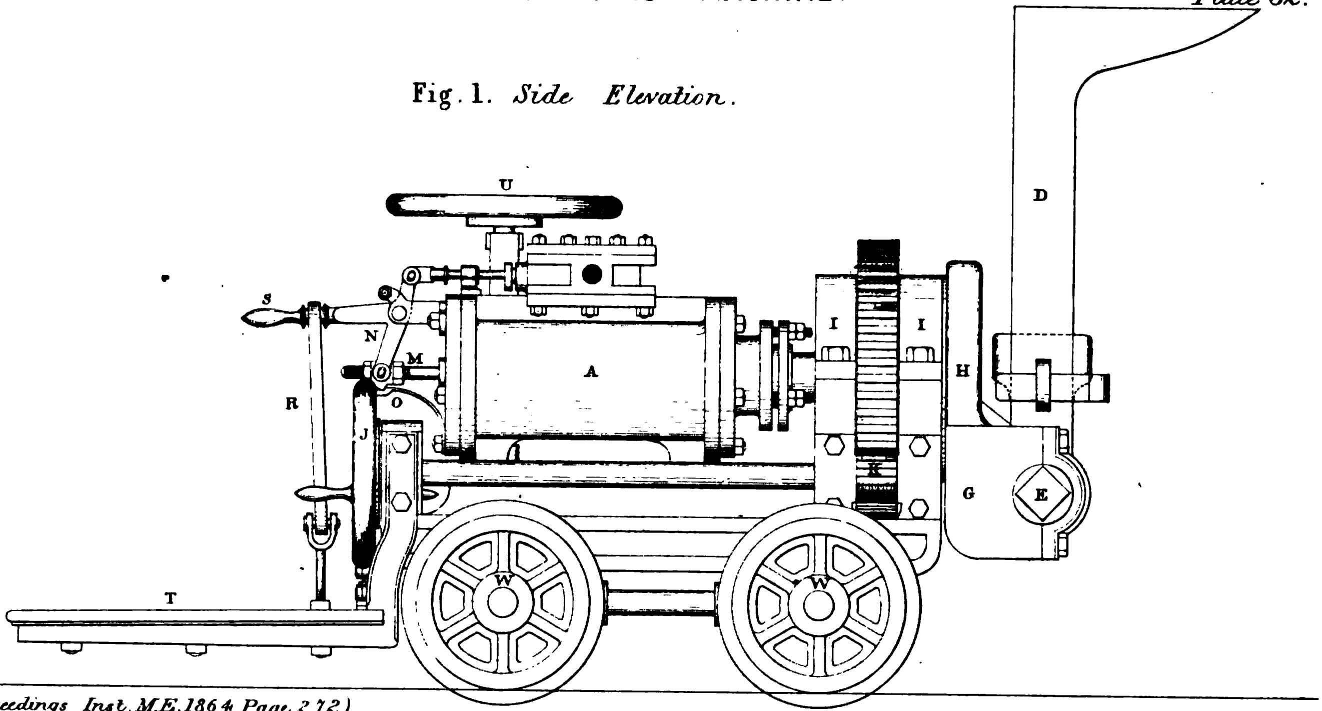
Fig. 5. *Acklam.*



(Proceedings Inst. M.E. 1864. Page 249) *Scale 1/140th*

COAL CUTTING MACHINE.

Fig. 1. *Side Elevation.*



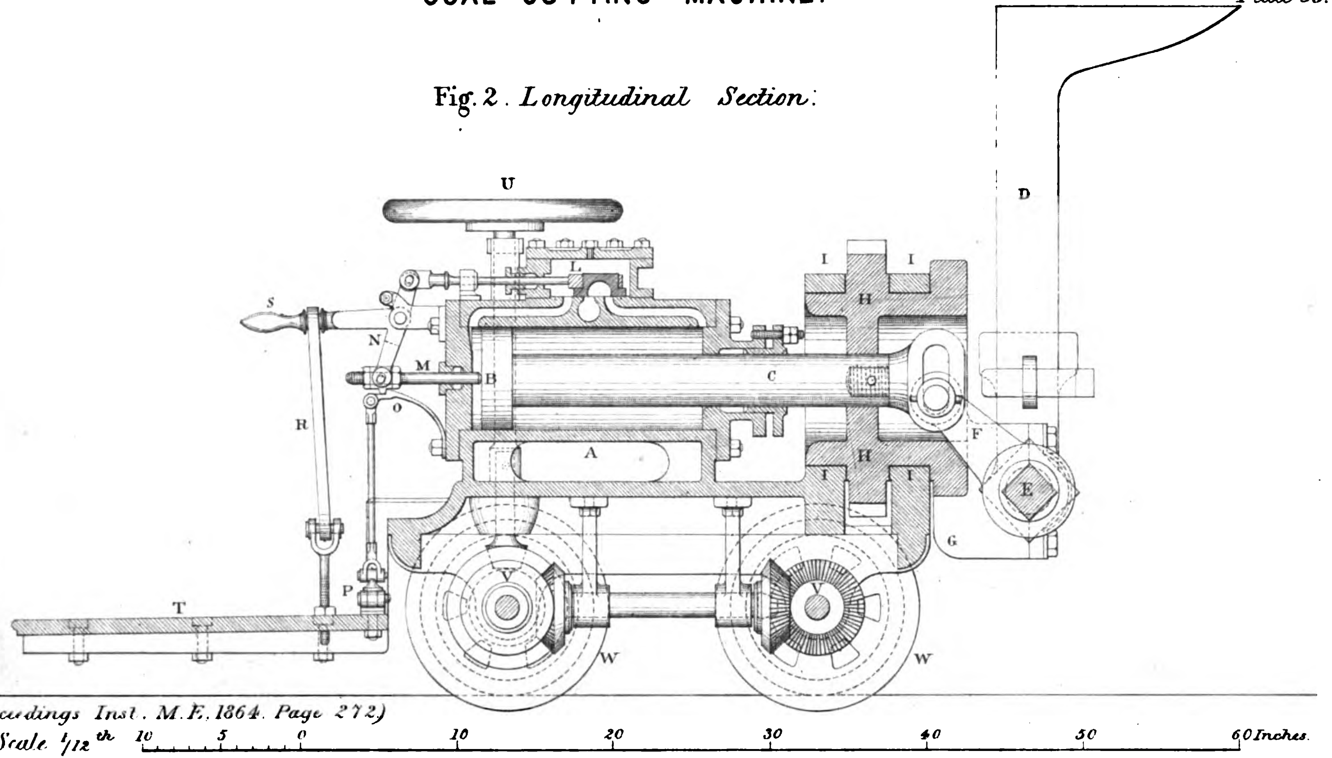
(Proceedings Inst. M.E. 1864. Page 272)

Scale 1/12th 10 5 0 10 20 30 40 50 60 Inches

Plate 83.

COAL CUTTING MACHINE.

Fig. 2. *Longitudinal Section.*

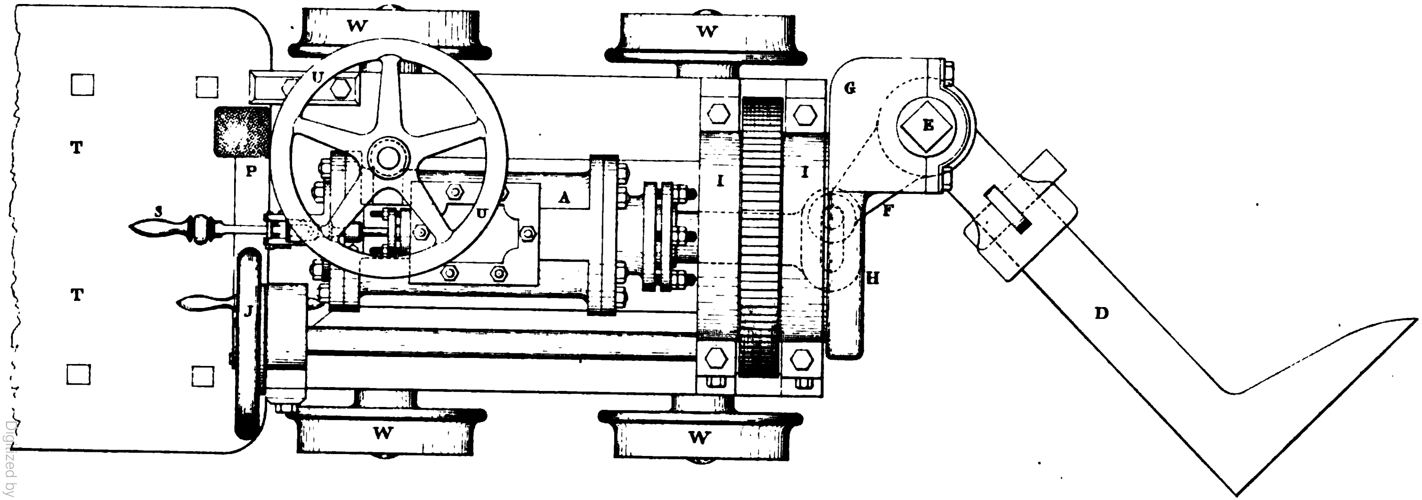


(Proceedings Inst. M.E. 1864. Page 272.)

Scale 1/12th

COAL CUTTING MACHINE.

Fig. 3. *Plan.*



(Proceedings Inst. M. E. 1864. Page 272)

Scale $1/12$th 10 5 0 10 20 30 40 50 60 Inches.

COAL CUTTING MACHINE.

Plate 85.

Fig. 4. *Plan of Tail Piece of Coal Cutting Machine. Scale 1/24th.*

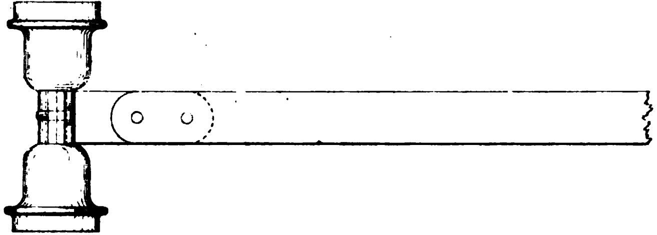
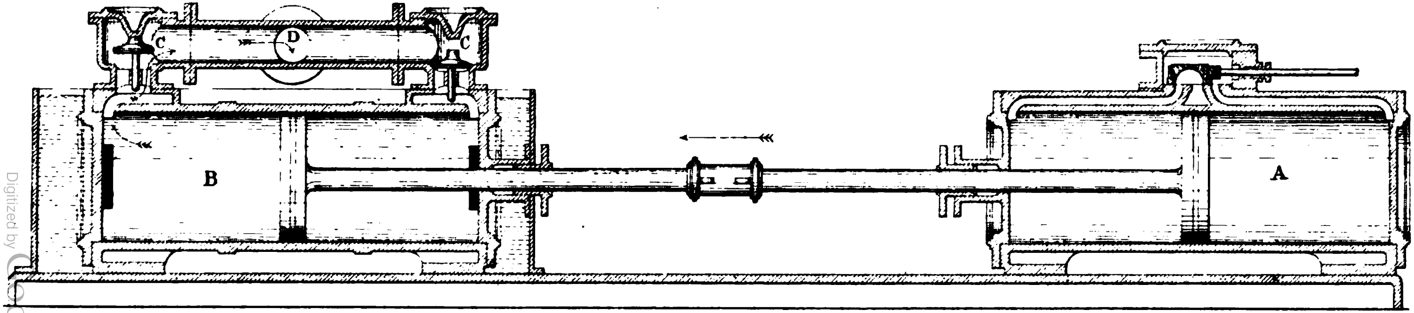


Fig. 5. *Longitudinal Section of Air-Compressing Engine.*



(Proceedings Inst. M. E. 1864. Page 272.)

Scale 1/24th. Ins. 12 6 0 1 2 3 4 5 6 7 8 9 10 Feet.

COAL CUTTING MACHINE. *Plate 86.*

Fig. 6. *Pick in position for Holing.*

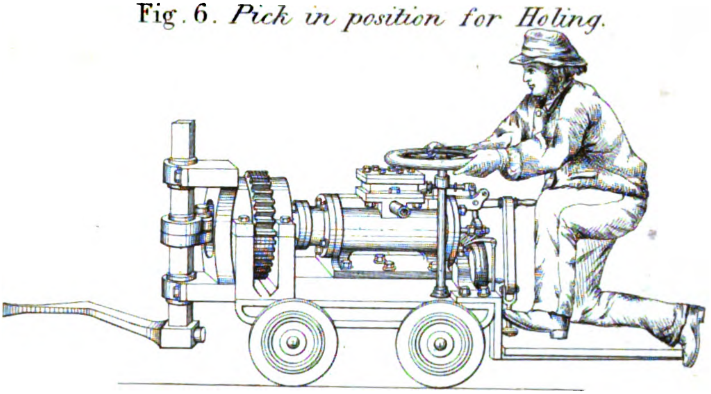


Fig. 7. *Pick in position for Vertical Cut Downwards.*

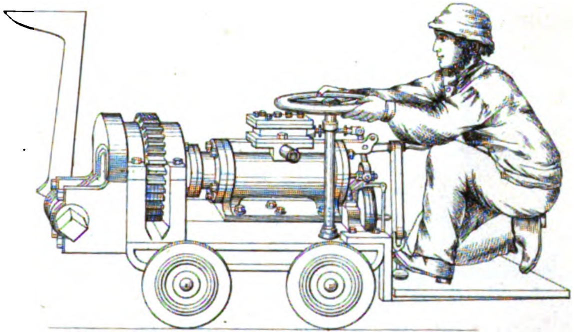
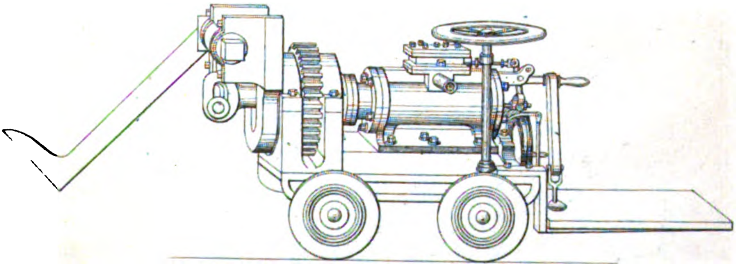


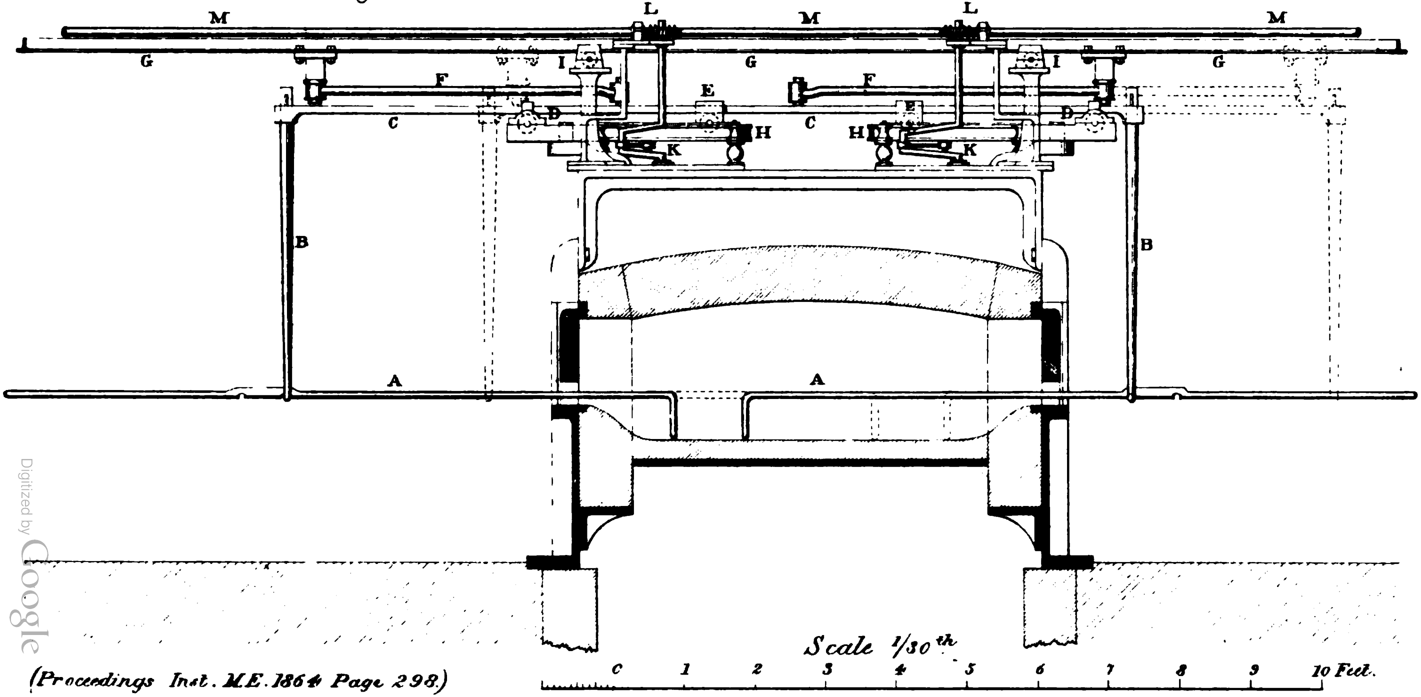
Fig. 8. *Pick in position for Vertical Cut Upwards.*



(Proceedings Inst. M.E. 1864. Page 272.)

PUDDLING MACHINE.

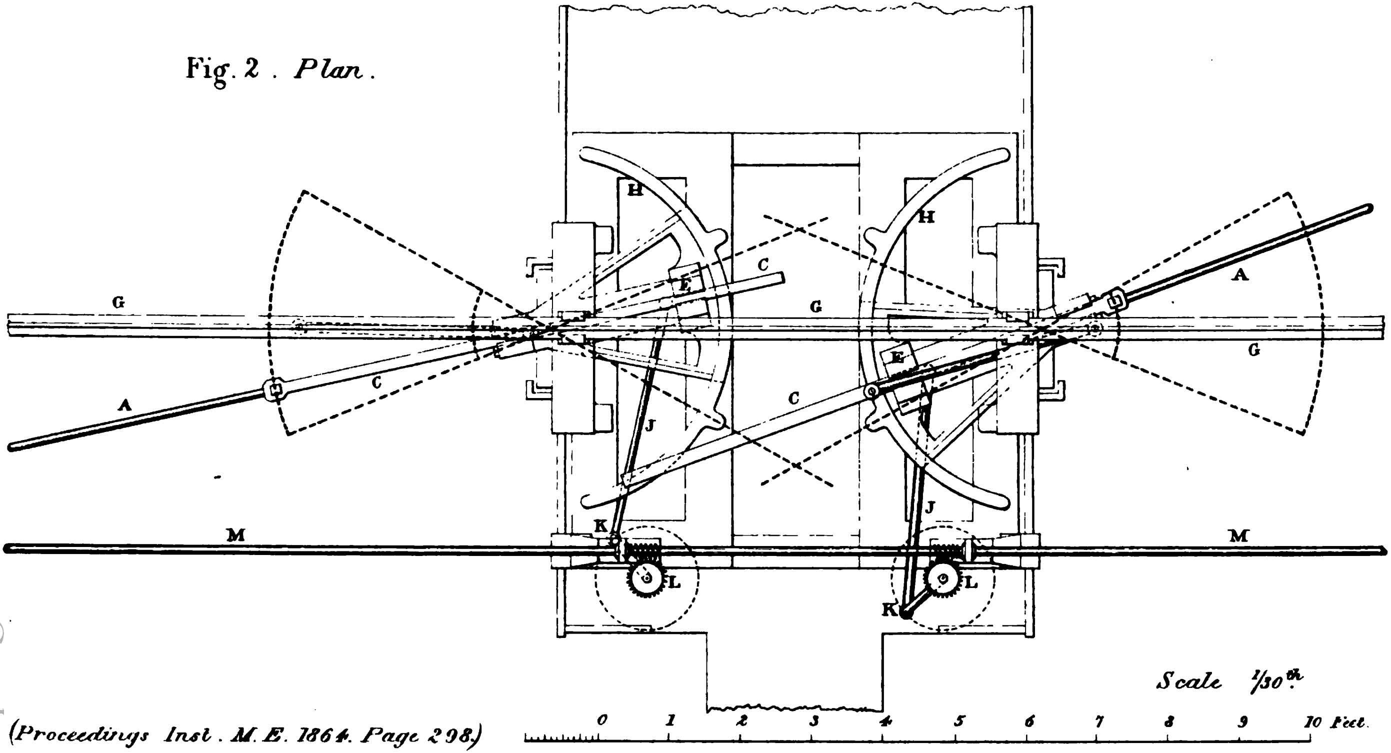
Fig. 1. *Transverse Section of Puddling Furnace.*



(*Proceedings Inst. M.E. 1864 Page 298.*)

PUDDLING MACHINE.

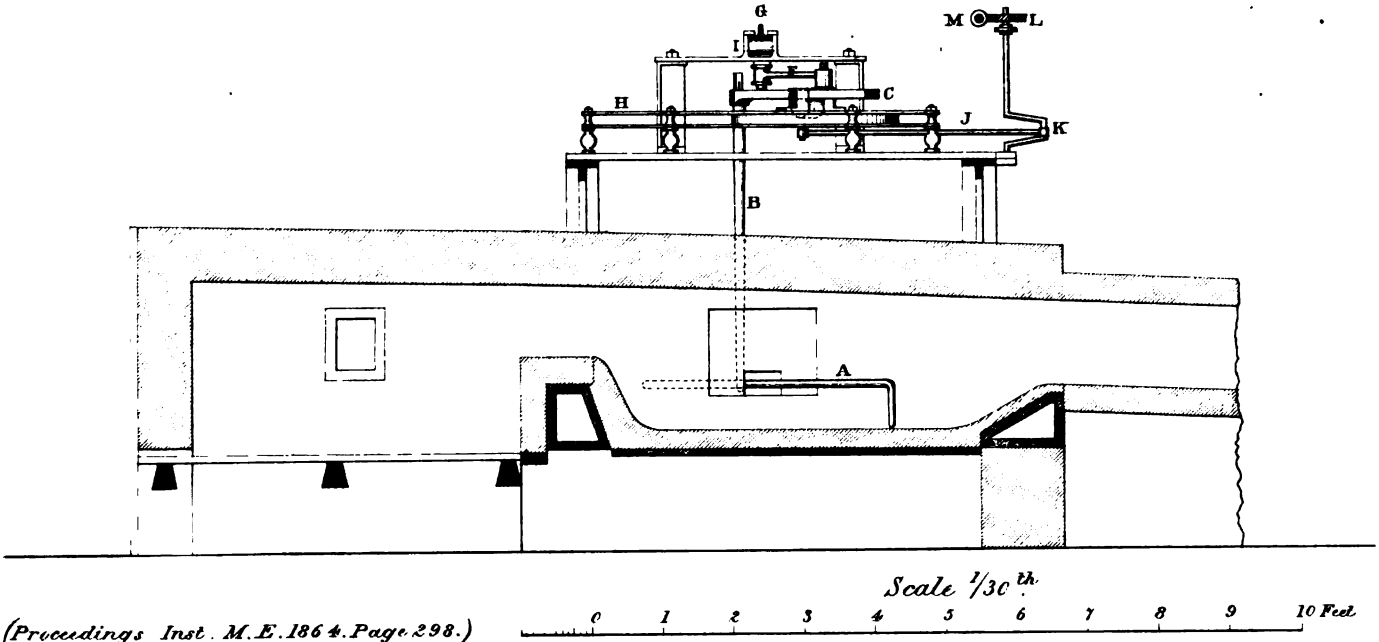
Fig. 2. Plan.



(Proceedings Inst. M. E. 1864. Page 298.)

PUDDLING MACHINE.

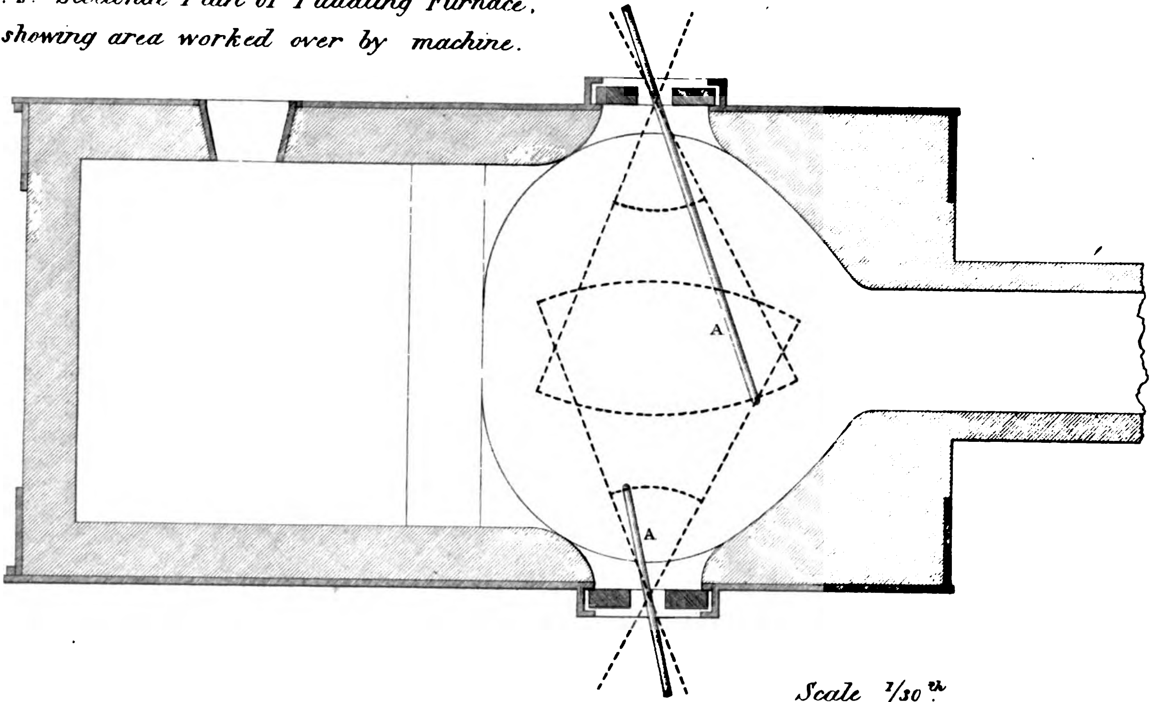
Fig. 3. *Longitudinal Section of Puddling Furnace.*



(Proceedings Inst. M.E. 1864. Page 298.)

PUDDLING MACHINE.

Fig. 4. *Sectional Plan of Puddling Furnace, showing area worked over by machine.*



Scale 1/30th

(Proceedings Inst. M.E. 1864. Page 298.)

3 9015 06701 7288